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Fugitive Emissions from Iron Foundries

Midwest Research Inst, Kansas City, MO

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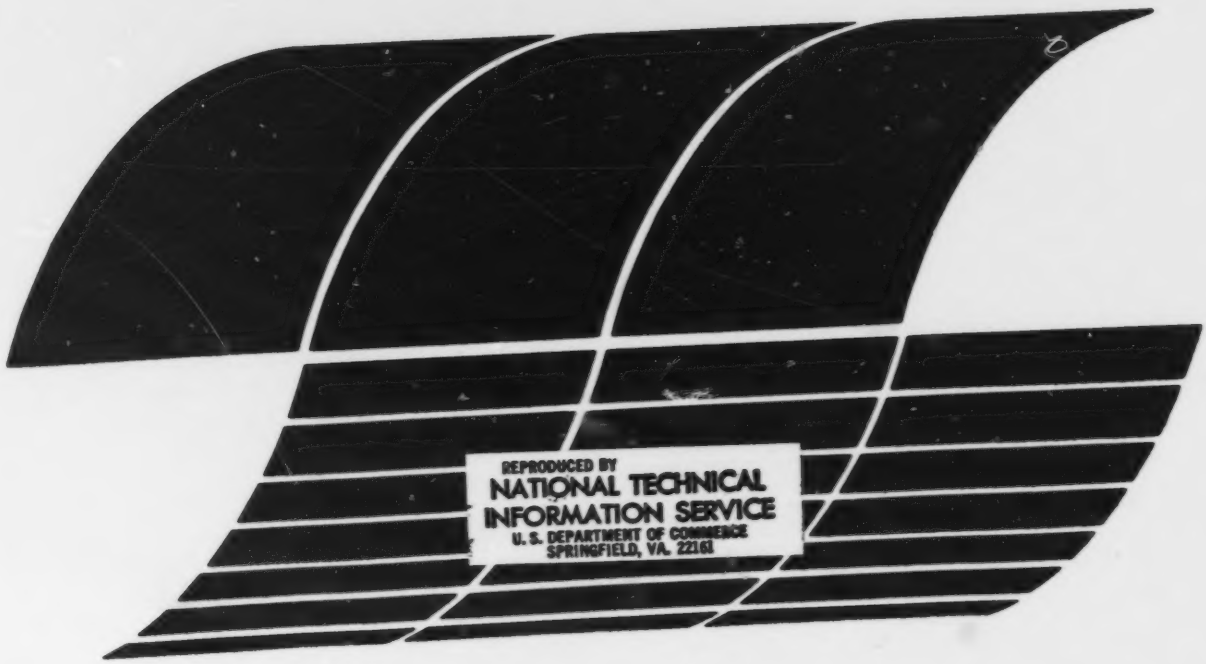
Interagency Energy/Environment R&D Program Report



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16. ABSTRACT The report describes the assessment of fugitive emissions of air pollutants discharged from process operations in iron foundries, and the need for the development of control technology for the most critical sources. Data indicates that the most significant fugitive emissions control problem in foundries is the pouring of hot metal into sand molds and the subsequent cooling of castings of these molds. Other significant fugitive emissions sources which have control problems are the electric arc furnace, preparation of molds and cores using organic binders, and casting shakeout. These conclusions are tempered by the fact that, for most fugitive emission sources in iron foundries, data is insufficient to determine accurate emission factors. Research and development programs are recommended: to better quantify the most significant sources; to evaluate currently available control technology for electric arc furnaces and shakeout; and to develop new control technology for pouring and cooling and for core and mold preparation using organic binders.

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PREFACE

This report was prepared for the Environmental Protection Agency to present the results of work performed under Contract No. 68-02-2120. Mr. Robert V. Hendriks served as EPA Project Manager.

The program was conducted in the Environmental and Materials Sciences Division of Midwest Research Institute. Dr. Chatten Cowherd, Head, Air Quality Assessment Section, served as Program Manager. Mr. Dennis Wallace was the principal investigator on the iron foundry portion of the study, which is the subject of this report.

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SUMMARY

The study reported herein was directed to the assessment of fugitive emissions of air pollutants discharged from process operations in iron foundries, and the need for the development of control technology for the most critical sources. The major study tasks included (a) identification and quantification of fugitive emissions based on available data; (b) prioritization of sources according to the need for emissions control; (c) analysis of current control practices and deficiencies in control technology; and (d) recommendation of research and development programs to provide the required control technology.

It was found that the most significant fugitive emissions control problem in foundries is the pouring of hot metal into sand molds and the subsequent cooling of castings of these molds. Other significant fugitive emissions sources which have control problems are the electric arc furnace, preparation of molds and cores using organic binders, and casting shakeout. Research and development programs are recommended (a) to better quantify the most significant sources; (b) to evaluate currently available control technology for electric arc furnaces and shakeout; and (c) to develop new control technology for pouring and cooling and for core and mold preparation using organic binders.

CONCLUSIONS

The major conclusions derived from this investigation are as follows:

1. For most fugitive emissions sources in iron foundries, data are insufficient to determine accurate emission factors with a high level of confidence.

2. Accurate emissions testing methods for fugitive emissions sources in foundries have not been adequately developed.

3. Many fugitive emissions sources, especially those involving sand handling and preparation, are well controlled in most foundries for worker health reasons.

4. By far, the most significant fugitive emissions control problem in foundries is the pouring of hot metal into sand molds and the subsequent cooling of castings in these molds.

5. Other significant fugitive emissions sources which have control problems are the electric arc furnace, preparation of molds and cores using organic binders, and casting shakeout.

6. Little research on iron foundry fugitive emissions problems is currently being conducted. The major exceptions are a NIOSH study on control methods employed at the best controlled foundries and a multimedia study by the Environmental Protection Agency. The results of these studies should be carefully reviewed.

7. Research and development programs are recommended (a) to better quantify the most significant sources; (b) to evaluate currently available control technology for electric arc furnace and shakeout and (c) to develop new control technology for pouring and cooling and for core and mold preparation using organic binders.

SECTION 1.0

INTRODUCTION

Until recently the national effort to control industrial sources of air pollution has focused on emissions discharged from stacks, ducts or flues and carried to the point of discharge in confined flow streams. Control strategies have been based on the assumption that the primary air quality impact of industrial operations resulted from the discharge of air pollution from conventional ducted sources.

However, failure to achieve the air quality improvements anticipated from the control of ducted emissions has spurred a detailed reexamination of the industrial air pollution problem. Evidence is mounting which indicates that fugitive (non-ducted) emissions contribute substantially to the air quality impact of industrial operations and, in certain industries, may greatly exceed the effects of stack emissions.

Iron foundry processes, which are characteristically batch or semicontinuous operations, entail the generation of substantial quantities of fugitive emissions at numerous points in the process cycle. Frequent materials handling steps occur in the storage and preparation of raw materials and in the disposal of process wastes. Additionally, fugitive emissions escape from reactor vessels during charging, process heating, and tapping.

Fugitive emissions occurring in iron foundries constitute a difficult air pollution control problem. Emissions are discharged with a highly fluctuating velocity into large volumes of carrier gases having poorly defined boundaries. Emissions from reactor vessels contain large quantities of fine particulate with smaller amounts of vaporous metals and organics in hot, corrosive gas streams. Enclosures and hooding of fugitive sources, with ducting to conventional control devices, have met with limited success in controlling emissions.

This report presents the results of an engineering investigation of fugitive emissions in the iron foundry industry. This study was directed to the accomplishment of the following objectives:

1. Identification of fugitive emission sources within integrated iron foundries.

2. Prioritization of identified emissions sources based on relative environmental impact.

3. Recommendations of future research, development and/or demonstration to aid in the reduction of fugitive emissions from the sources determined to be the most critical.

Fugitive emissions in the iron foundry industry generally come from one of five process areas: (a) raw materials storage and handling; (b) melting and casting; (c) finishing; (d) core and mold preparation; and (e) waste materials handling. A complete listing of the sources is given in Table 1-1.

The technical approach used to conduct the subject investigation consisted of the performance of the following seven program tasks:

Task 1 - Identify Fugitive Emission Sources: A comprehensive information collection and data compilation effort was carried out to identify all potentially significant sources of fugitive emissions occurring within iron foundries.

Task 2 - Quantify Fugitive Emissions: Available emissions data based on source tests and estimating techniques were used to characterize the types and quantities of fugitive emissions from sources identified in Task 1.

Task 3 - Review Existing Control Technology: Information was collected and analyzed to evaluate the effectiveness of available systems and techniques applicable to the control of fugitive emissions.

Tasks 4 and 5 - Develop Emissions Classification System and Classify Emissions: A generic classification system was developed and applied to identify the similarities and differences in fugitive emission sources, thereby defining generalized control problems which might most effectively be treated in an integral manner.

Task 6 - Determine Critical Control Needs: Using background information developed in previous tasks, the identified fugitive sources were ranked according to their relative environmental benefit of (or need for) emissions control requiring, if necessary, the development and demonstration of effective control techniques.

Task 7 - Recommend Research and Development Programs: Having identified and prioritized control needs in Task 6, priority R and D program areas were recommended to address these needs, taking into account deficiencies in available control technology and the expected results of research programs already underway.

TABLE 1-1. SOURCES OF FUGITIVE EMISSIONS FROM IRON FOUNDRIES

1.0 Raw Materials Storage and Handling
- 1.1 Storage
  - Coke
  - Sand
  - Scrap
- 1.2 Handling and Transfer
  - New sand handling
  - Spent sand handling
  - Coke handling

2.0 Melting and Casting
- 2.1 Cupola
  - Tapping
- 2.2 EAF
  - Charging
  - Tapping
  - Leakage
- 2.3 Induction Furnace
- 2.4 Inoculation
- 2.5 Pouring and Cooling

3.0 Finishing
- 3.1 Shakeout
- 3.2 Grinding

4.0 Core and Mold Preparation
- 4.1 Mulling
- 4.2 Shell or hot box
  - Heating
  - Holding pallet
- 4.3 Cold set box
- 4.4 Core wash

5.0 Waste Handling
- 5.1 Slag quench
- 5.2 Waste sand transfer
- 5.3 Sand and slag storage

This report is organized by subject area as follows:

- Section 2 identifies fugitive emission sources within iron foundries.
- Section 3 presents data on the quantities of fugitive emissions.
- Section 4 summarizes control technology applicable to fugitive emissions sources.
- Section 5 presents a ranking of critical control needs and defines priority R&D program areas directed to the development of control technology for fugitive emissions.
- Section 6 lists the references cited in this report.
- Section 7 presents a Glossary of Terms which defines special terminology used in this report to describe and characterize fugitive emission sources.
- Section 8 is an English to metric conversion table.

SECTION 2.0

FUGITIVE EMISSION SOURCE IDENTIFICATION

The iron foundry industry utilizes iron and steel scrap to manufacture cast iron products ranging in size from less than an ounce to several tons per casting. Many of the processes involved in the production of castings have the potential for release of gaseous and/or particulate fugitive emissions to the foundry environment and subsequently to the external atmosphere. The first two subsections below describe the basic foundry processes and identify those sources which have fugitive emissions potential. Industry-wide materials flow is developed in the final subsection.

2.1 GENERAL PROCESS DESCRIPTION

The typical iron foundry processes various grades of iron and steel scrap to produce iron castings. For the remainder of the report, any foundry which produces gray, ductile or malleable iron will be considered an iron foundry. This classification is reasonable in that most processes used to produce the three types of iron are identical. Also, the chemical specifications for gray iron shown in Table 2-1 nearly encompass those for ductile and malleable iron given in the same table.

The four basic operations present in all foundries are: raw materials handling and storage, melting, pouring of metal into molds and removal of castings from the molds. Other operations present in many but not all foundries include: (a) preparation and assembly of molds and cores; (b) mold cooling; (c) shakeout; (d) casting, cleaning, and finishing; (e) sand handling and preparation; and (f) hot metal inoculation.

For purposes of this report the iron foundry has been divided into five areas of operation:

1. Raw materials storage and handling.

2. Melting and casting.

3. Cleaning and finishing.

TABLE 2-1. CHEMICAL SPECIFICATIONS FOR IRON CASTINGS[1/]

Element	Gray iron (%)	Malleable iron (cast white) (%)	Ductile iron (%)
Carbon	2.5-4.0	2.00-2.60	2.4-4.0
Silicon	1.0-3.0	1.10-1.60	1.8-2.8
Manganese	0.25-1.0	0.20-1.00	0.10-1.00
Sulfur	0.02-0.25	0.04-0.18	0.03 maximum
Phosphorus	0.05-1.0	0.18 maximum	0.10 maximum

4. Mold and core preparation

5. Waste handling

A general flow diagram of foundry operations is presented in Figure 2-1. Block diagrams of each of the first four basic areas are presented in Figures 2-2 to 2-5. A separate figure (Figure 2-6) is presented for sand handling, which may be involved in all areas of operation. It should be noted that while most iron foundries have operations falling into each of the broad categories listed above, the foundry industry is so diverse that specific operations will vary greatly from plant to plant. Described below are the operations most commonly utilized in iron foundries.

As can be seen in Figure 2-1, raw materials enter the foundry in one of two areas, the melt shop or the core and mold-making area. At the melt shop the primary raw materials are iron scrap, borings and turnings, limited quantities of pig iron and foundry returns used for metallic content, coke for cupolas and fluxing material such as limestone, dolomite, fluorspar, and calcium carbonate. The metallics are generally melted in one of three furnace types: cupola, electric arc or electric induction furnace. Reverberatory or air furnaces are currently in limited use. After the iron is melted, required ladle additions are made, either in the furnace or the ladle, and the iron is transferred by ladle to the pouring area for casting in molds.

Upon reaching the casting area, the hot metal is poured into a mold to produce an iron casting. The four types of molding processes which have received most attention are green sand molds, shell sand molds, cold set molds and permanent molds or centrifugal casting. Of these, green sand molding is by far the most prevalent. Reference 2 discusses dry sand molding, the full mold process and the Rheinstahl process; however, they were not examined as a part of this study. If a sand mold is used, the mold and casting are then transferred to a shakeout area where the casting is removed from the sand. The spent sand is then recycled and the casting is taken to the finishing shop for cleaning, grinding and finishing.

Further descriptions of the specific foundry operations are included in the following section on sources of iron foundry fugitive emissions.

2.2 FUGITIVE EMISSIONS SOURCES

Iron foundries contain a variety of process sources with the potential for emitting gaseous or particulate air pollutants to the plant environment and on to the atmosphere. As indicated in Section 2.1, specific operations differ greatly in different foundries. Hence the specific operations which present an emissions problem in one foundry may not be a problem in another foundry.

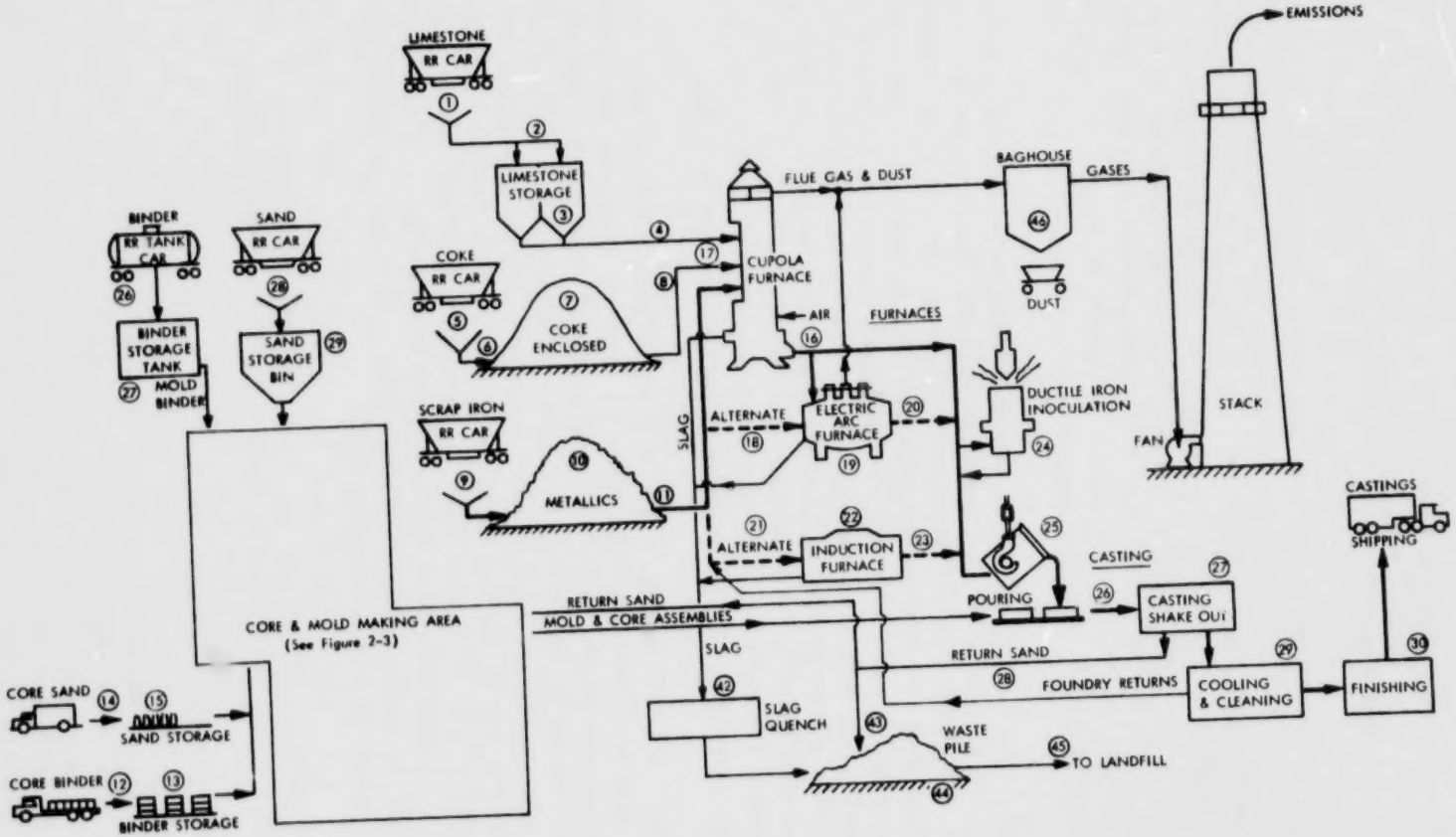


Figure 2-1. Composite flow diagram for the gray iron foundry industry. (Numbers refer to source listings in Table 2-2.)

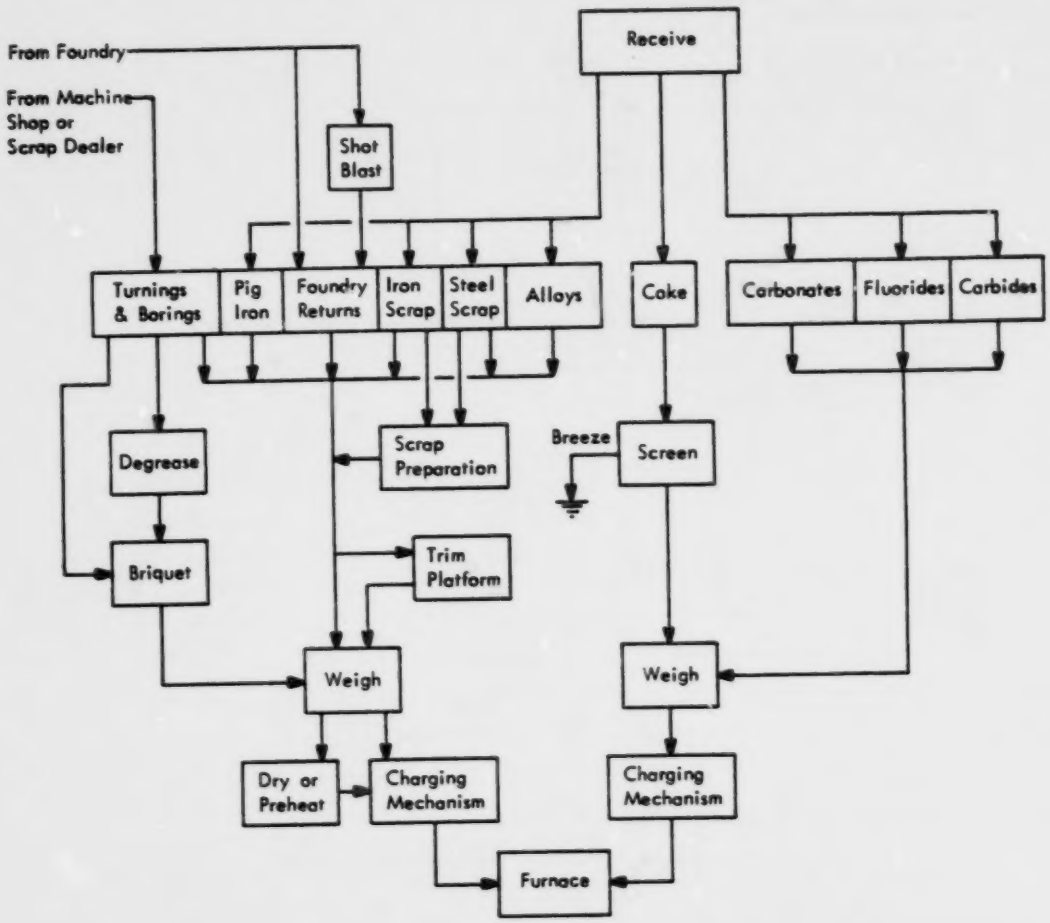


Figure 2-2. Raw material storage and handling.[2/]

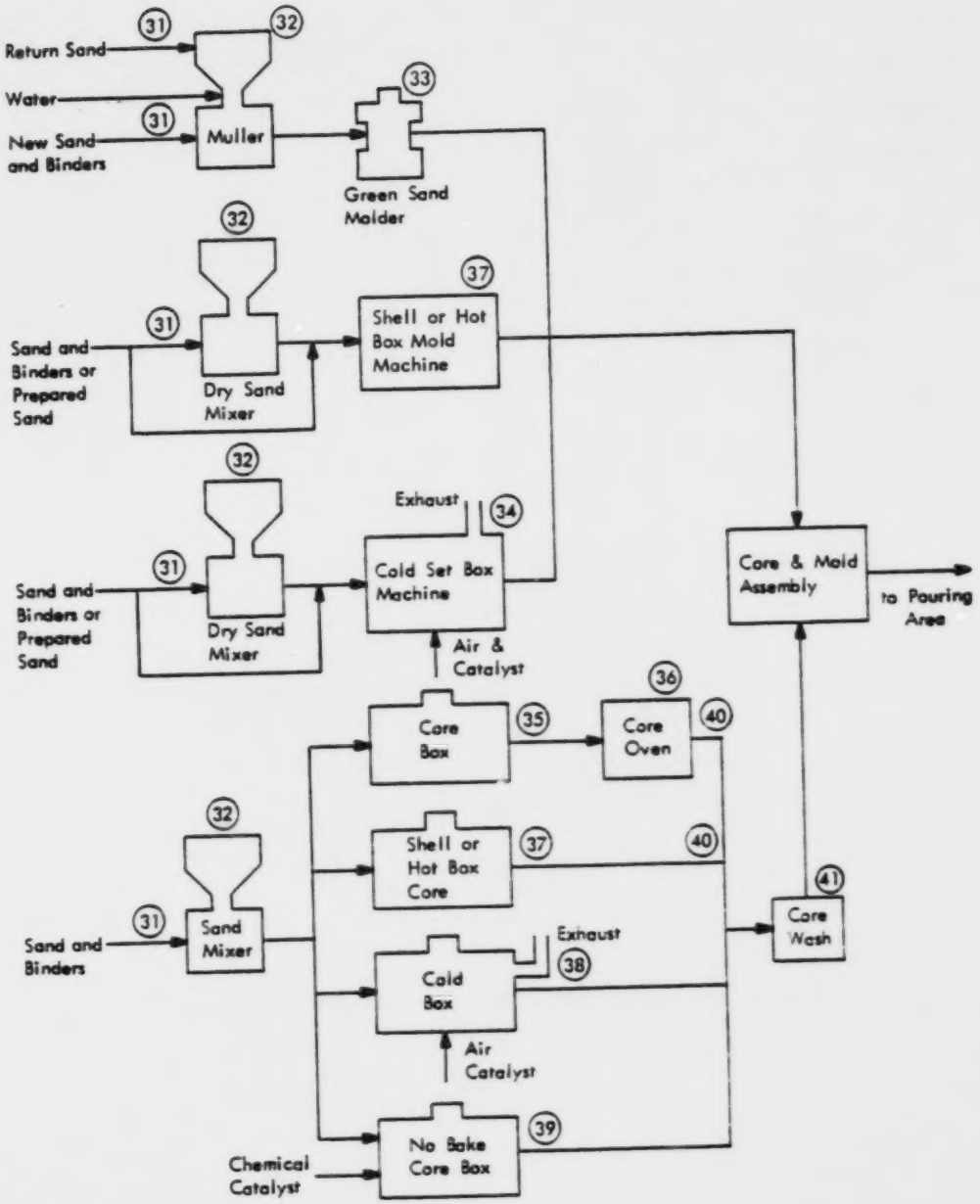


Figure 2-3. Mold and core making. (Numbers refer to Table 2-2.)

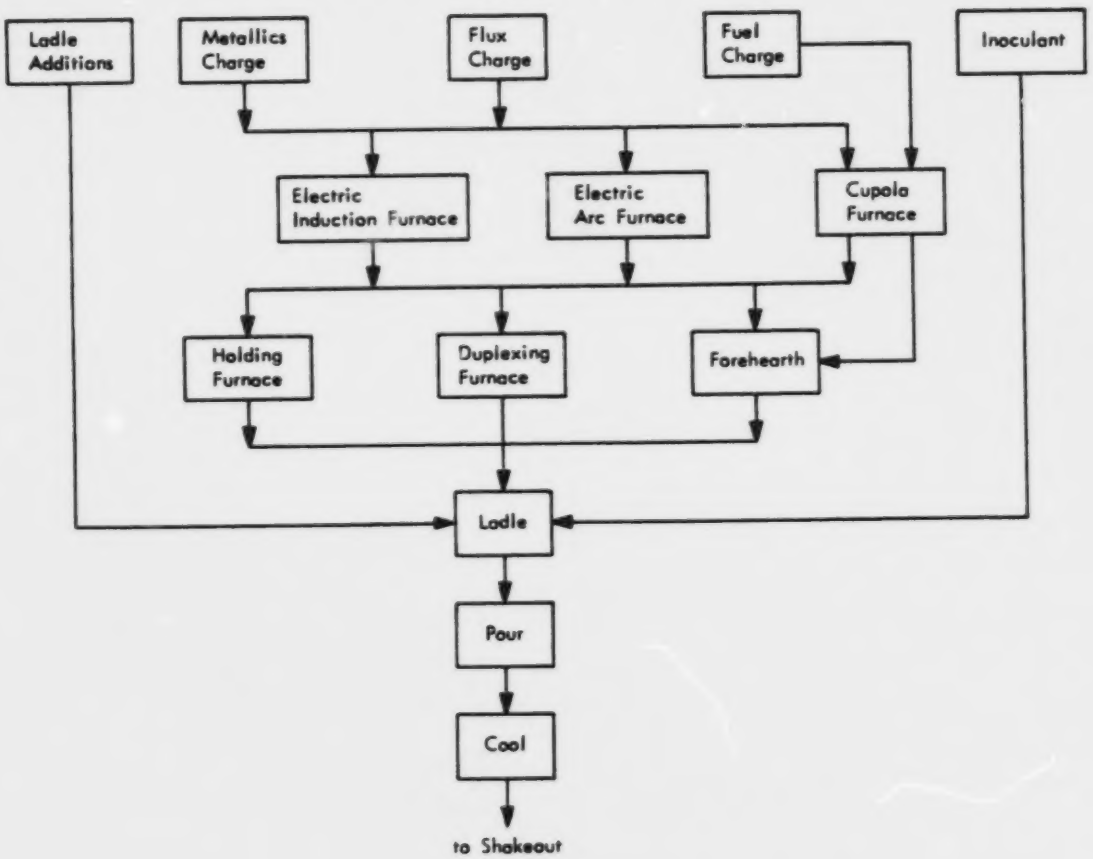


Figure 2-4. Melting and casting.[3/]

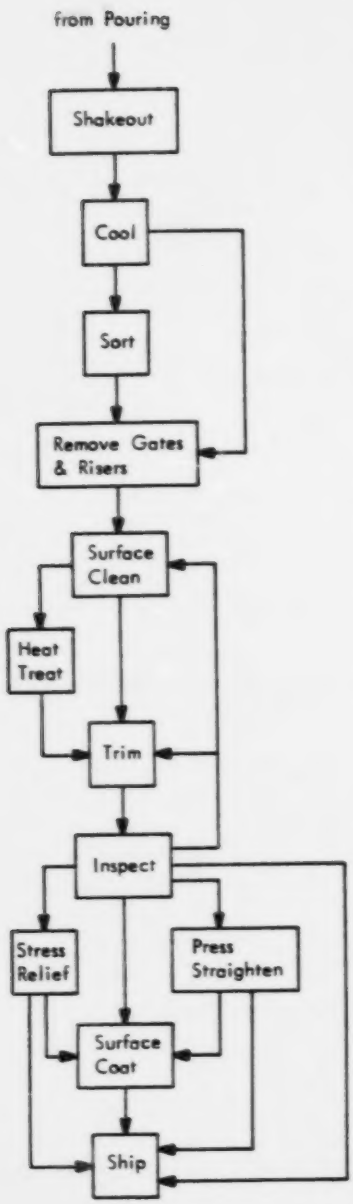


Figure 2-5. Cleaning and finishing.[4/]

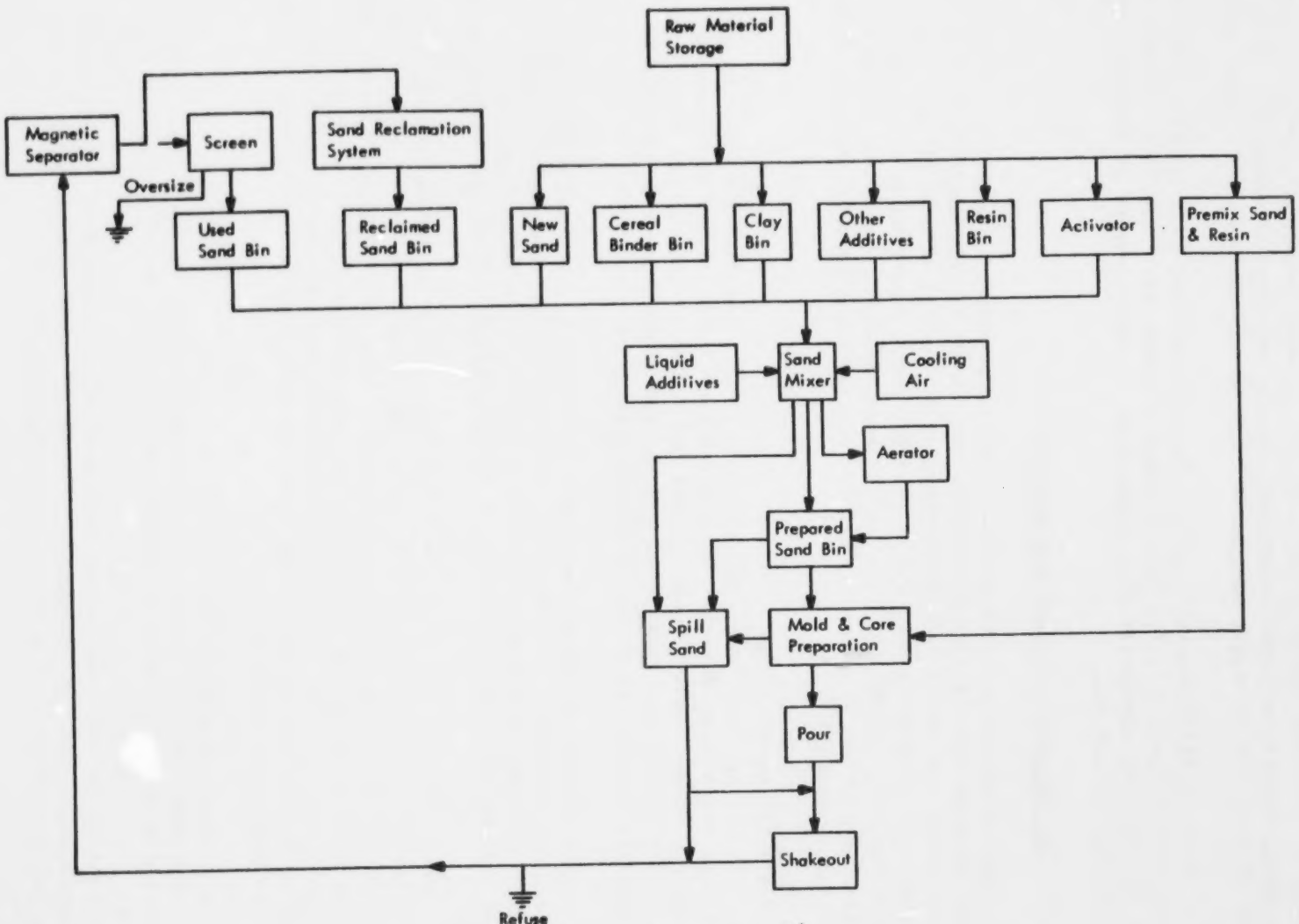


Figure 2-6. Sand handling.[5/]

Based on a limited number of contacts with industry personnel, probable sources of fugitive emissions were identified and are presented in Table 2-2. Obviously, all of these are not major sources of fugitive emissions in the foundry industry.

Those fugitive sources which may be major sources at a specific plant are presented in Table 2-3. For each of these sources, available data on composition of the emission stream are also given. Each of these sources is discussed in the following subsections.

2.2.1 Raw Materials Storage and Handling

Raw materials are used in two areas of the foundry. Metallics and possibly coke and some type of fluxing material are needed for the production of molten iron in the melt shop. Sand and binders or a prepared mixture of sand with binders are needed for mold and core preparation. Depending upon the method used, both the storage and handling of these materials may become a fugitive emissions problem. However, appropriate processing and storage methods should minimize emissions.

2.2.1.1 Storage--

The primary materials entering storage are: (a) the sand which is used for core and mold production, (b) various grades of scrap to be charged as metallics to the furnace, and (c) coke for firing of the cupola. Minor quantities of fluxing materials, refractories and binders are also received by foundries. However, these are of little significance as emission sources.

Generally foundries purchase mold and possibly core sand which is washed, dried, and screened before shipping. Upon receipt the sand is transferred by covered conveyor or pneumatic tube to an enclosed storage area to preserve sand quality. Hence new sand storage should present minimal emissions problems.

Coke and scrap arrive at the foundry by railcar or truck. These have traditionally been stored in open scrapyards. However, many foundries now have covered storage areas to prevent degradation from weathering of both coke and scrap. Minimal emissions from storage of coke and dirty scrap may be generated during load-in and load-out from both open and covered storage. Wind erosion from open yards and those covered areas not having protection against the wind may generate some emissions.

2.2.1.2 Handling and Transfer--

The sand handling system shown in Figure 2-6 can be the largest source of fugitive emissions in an iron foundry. However, many of these emissions are larger particles (> 50 μm in diameter) and so will settle out before leaving the foundry. As indicated above, sand is often transferred to storage areas pneumatically. However, if mechanical means are used, conveyor dump and transfer points will be sources of fugitive emissions.

TABLE 2-2. FUGITIVE EMISSION SOURCES IN IRON FOUNDRIES

Source No.[a]	Source identification	Pollutant: Particulate	Sulfur oxides	Carbon monoxide	Metal fumes	Hydrocarbons
Raw materials storage & handling						
	Limestone handling					
1	Unloading	X				
2	Transfer to storage	X				
3	Storage	X				
4	Transfer to furnace	X				
	Coke handling					
5	Unloading	X				
6	Transfer to storage	X				
7	Storage pile	X				
8	Transfer to furnace	X				
	Metallic charge handling					
9	Unloading	X				
10	Storage pile	X				
11	Transfer to furnace	X				
12	Binder unloading	X				X
13	Binder storage	X				X
14	Sand unloading	X				
15	Sand storage	X				
Melting & casting						
	Cupola furnace					
16	Tapping	X	X	X	X	
17	Charging	X		X		
	Electric arc furnace					
18	Charging	X				X
19	Leakage	X		X	X	
20	Tapping	X			X	
	Induction furnace					
21	Charging	X			X	X
22	Melting	X			X	X
23	Tapping	X			X	

(continued)

TABLE 2-2. (continued)

Source No.[a]	Source identification	Pollutant: Particulate	Sulfur oxides	Carbon monoxide	Metal fumes	Hydrocarbons
24	Iron inoculation	X			X	
25	Pouring	X			X	X
26	Cooling	X			X	X
	Cleaning & finishing					
27	Shakeout	X			X	X
28	Return sand system	X				
29	Cooling & cleaning	X				
30	Grinding	X				
	Mold & core preparation					
31	Sand charge to mixer/muller	X				
32	Dry sand mixing or mulling	X				
33	Molder					X
34	Cold set mold					X
35	Oven bake core box	X				X
36	Core oven leakage					X
37	Shell or hot box heat					X
38	Cold box core or mold					X
39	No bake core box					X
40	Core cooling					X
41	Core wash	X				X
	Waste handling					
42	Slag quench	X	X			
43	Waste sand transfer	X				
44	Waste material storage	X				
45	Transfer to landfill	X				
46	Baghouse catch	X				

[a] Sources are identified by number in Figures 2-1 and 2-3.

TABLE 2-3. MAJOR SOURCES OF FUGITIVE EMISSIONS

Emissions source	Pollutant	Concentration[a] (uncontrolled)	Particle size distribution[a]
Raw material storage and handling			
Storage piles			
Sand	Particulate	3-5 gr/cu ft[6]	50% 2-15 μm[6]
Coke	Particulate	3-5 gr/cu ft[6]	30-1,000 μm[6]
Scrap	Particulate	3-5 gr/cu ft[6]	30-1,000 μm[6]
Handling and transfer			
Sand transfer to storage	Particulate	3-5 gr/cu ft[6]	50% 2-15 μm[6]
Sand transfer from storage to mold area	Particulate	3-5 gr/cu ft[6]	50% 2-15 μm[6]
Coke transfer	Particulate	3-5 gr/cu ft[6]	
Return sand conveyors	Particulate	1/2-2 gr/cu ft[6]	50% 7-15 μm[6] (90% > 50 μm)[9]
Mold and core preparation			
Mulling (charging and mixing)	Particulate	3-5 gr/cu ft[6]	50% 2-15 μm[6]
Shellcore and mold heat	CO	700 ppm[7]	
	Formaldehyde	10 ppm[7]	
	Amines	250 ppm[7]	
	Phenol	20 ppm[7]	
Cold set core			
Box exhaust	Amines	400-4,000 ppm[8]	
	Phenol	3-20 ppm[8]	
	Formaldehyde	5-15 ppm[8]	
Holding pallet	Amines	350-1,400 ppm[8]	
	Phenol	3-8 ppm[8]	
	Formaldehyde	3-5 ppm[8]	
Melting and casting			
Cupola tapping	Particulate	-	< 0.7 μm[6]
EAF charging	Particulate		80% < 5 μm[10]
	Hydrocarbon mist		0.1-1 μm[6]
Tapping	Particulate		80% < 5 μm[10]
Leakage	Particulate		80% < 5 μm[10]
Induction furnace (charging, tapping, and leakage)	Hydrocarbon	-	-
	Particulate	-	-

(continued)

TABLE 2-3. (continued)

Emissions source	Pollutant	Concentration[a] (uncontrolled)	Particle size distribution[a]
Iron inoculation	Particulate	Heavy[6]	< 0.7 μm[6]
Metal pouring	Particulate	0.00291 gr/scf[11]	98% < 15 μm[12] (97% < 6 μm)
	CO	1,500 ppm[11]	
	Hydrocarbon	250 ppm[11]	
Cooling	Particulate	0.00291 gr/scf[11]	98% < 15 μm[12] (97% < 6 μm)
Cleaning and finishing			
Shakeout	Particulate	0.1654 gr/scf[11]	98% < 15 μm[12] (46% < 6 μm)
	CO	670 ppm[11]	
	Hydrocarbon	215 ppm[11]	
Grinding	Particulate	0.5-5 gr/scf[6]	-
Waste handling			
Slag quench	Particulate	-	-
	SO_2	-	-
Waste sand transfer	Particulate	-	-
Sand and slag storage	Particulate	-	-

a/ Superscripts refer to references in Section 6.

As cereal and clay binders are added to the sand this will increase the amount of fines and hence the potential for emissions. As sand and binders are mixed in the muller, they are generally wetted, and emissions are not generated for the remainder of the preparation process. After shakeout, the spent sand is again dry and has the potential for emissions. All conveyor drop points and screening and reclamation operations will be sources of fugitive emissions.

Methods for handling scrap and, in foundries using cupolas, coke vary greatly. Smaller, older foundries may transfer materials manually using forklifts and buckets and hand charging while larger foundries may have a completely mechanized materials handling system. In either case the amount of emissions is dependent upon the quality of the scrap or coke. If the scrap or coke contain significant amounts of fines, vibrating conveyors, conveyor drop points, and manual materials dumps will all be sources of fugitive emissions. However, handling of coke and scrap is generally a minor source of emissions.

2.2.2 Melting and Casting

The operations that occur in an iron foundry from the time scrap is charged into a furnace for melting until the time the casting is to be removed from the mold constitute the greatest fugitive emission sources for which generally applicable control measures have not been identified. Most iron castings are produced from scrap which has been melted in either a cupola, an electric arc furnace (EAF), or an electric induction furnace. The primary fugitive emission sources from melting are (a) cupola tapping; (b) the total EAF cycle; and (c) induction furnace charging and melting. Other major emission sources in this area include (a) inoculation of ductile iron, (b) pouring hot metal into molds, and (c) cooling the filled molds before shakeout.

2.2.2.1 Cupola--

The cupola furnace is an upright brick-lined cylindrically shaped vessel which uses the heat from the charged coke to melt iron. The cupola operation is continuous, with metallics, coke and fluxing agents being charged in layers at the top and the molten iron tapped from the bottom. The operation and primary emissions problems of the cupola are described in detail in Reference 13 and are not discussed here.

Because the cupola is kept under negative pressure for emission control purposes, charging is generally not a fugitive emissions problem. The only source of fugitive emissions is the tapping of the molten metal from the furnace. The metal is tapped in one of two ways. In the first case, the metal is tapped to a forehearth where the slag is skimmed and then the iron is transferred into a ladle for pouring. In this case, the slag skimming and transfer into the ladle are minor sources of fine particulate emissions. In the other case, the metal is tapped directly to a ladle and the slag is skimmed from the ladle. This is also a minor source of fine particulate emissions.

2.2.2.2 Electric Arc Furnace--

The electric arc furnace (EAF) is a refractory-lined cup-shaped vessel with a refractory-lined roof. Three graphite electrodes are placed through holes in the roof to provide the electrical energy for melting iron. The EAF can be charged through the side, or the roof can be removed and the furnace charged from the top. Most newer and larger furnaces are of the top charge variety.

Primary emissions control for the EAF during melting is generally accomplished through some form of direct shell evacuation (DSE) or by the use of a canopy hood. The problem with the DSE system is that it is not operational when the roof is removed for charging or tapping, both of which are considered to be major sources of fugitive particulate emissions. Also, if oily scrap is charged to the EAF, charging can be a source of hydrocarbon emissions. It is also possible to have a small amount of leakage around the electrodes during melting, but this is a relatively minor source of emissions if the primary system is operating properly. However, malfunction or inferior design of the primary DSE system can lead to a major fugitive emissions problem.

In the case where a canopy hood is used as the primary emissions control system, emissions from all phases of the operation are captured to some degree. However, inefficient capture can result from cross drafts and cause significant quantities of emission to escape. This constitutes a major fugitive emissions problem.

2.2.2.3 Electric Induction Furnace--

The two types of induction furnaces used in foundries are the channel induction and coreless induction furnaces. The coreless induction furnace is most often used for iron melting and this type presents the more significant fugitive emission problem. The coreless induction furnace is a cup-shaped vessel which uses electrical energy to induce eddy currents in the metallic charge to produce molten iron. Since very clean or preheated scrap must be charged to the induction furnace, emissions are generally less than the cupola or the EAF. Hence, these furnaces are often uncontrolled. In that case, the total furnace operation becomes a fugitive emission problem.

2.2.2.4 Iron Inoculation--

Approximately 15% of the iron castings produced in the United States utilize ductile iron. Generally, ductile iron is produced by the addition of magnesium or similar alloying compound to the molten iron after it has been tapped to the ladle. Several methods are used to introduce the magnesium to the molten metal. Several of these are illustrated in Figure 2-7. These methods are described in detail in Reference 14. Since the primary emissions from iron inoculation are magnesium oxide particulate, the severity of the emissions problem is related to the level of magnesium recovery of the particular process. Modl[14] indicates that three processes which have yielded good results and are widely applied are (a) pourover method, (b) sandwich methods, and (c) plunging method.

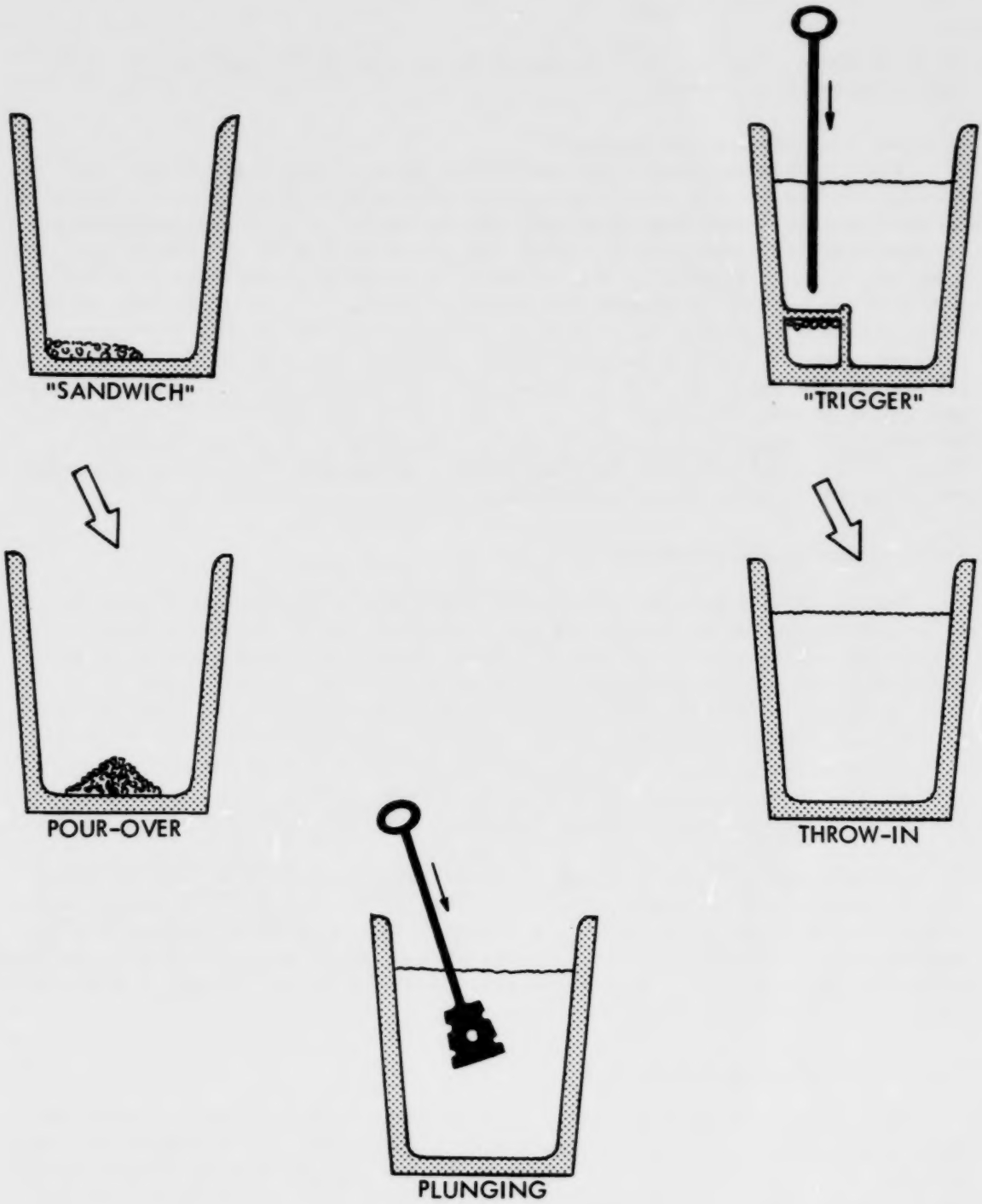


Figure 2-7. Methods of iron inoculation.[14/]

Of these three, sandwich methods appear to have the best magnesium recovery and hence least emissions.

2.2.2.5 Iron Pouring and Cooling--

Two of the most significant sources of fugitive emissions in the iron foundry are the pouring of hot metal into sand molds and subsequent cooling of the castings. These processes vary significantly in different foundries. In nonmechanized foundries, the molds are generally placed in a large open area. The hot metal ladle is then moved by a overhead pulley system to the mold and the casting is poured and cooled in place. In more mechanized foundries, the mold is placed on a conveyor and moved to the pouring station and then moved onto a cooling area. Emissions problems are comparable for both processes. The emissions are contained in a relatively high temperature, buoyant, moist stream. The constituents of the stream are fine metallics from the hot metal and organics produced by thermal decomposition of the binders, as discussed in Section 2.2.4. The damp buoyant stream and the organic emissions make control of these sources difficult.

2.2.3 Cleaning and Finishing

The only major sources of fugitive emissions in the finishing area are casting shakeout and grinding. Shakeout is the method by which the iron casting is removed from the sand mold. Shakeout varies more from plant to plant than any other foundry operation. Observations during a limited number of foundry visits revealed shakeout being accomplished manually by forklift or hand shovel, mechanically on a grate shakeout, and by elevating the flask and pneumatically shaking the sand and casting out. In any case the emissions consist of dust from the dried sand, organic residue from binders, and water vapor. Ease of control appears to be dependent upon the type of shakeout used.

Grinding may also be a source of fugitive emissions in an iron foundry. Four basic types of grinders are used in foundries: bench, floor stand, portable, and swing. Each of these is a source of particulate emissions. Little information was obtained on the partizle size or total amount of emissions from grinding. However, some plant operators indicated that the finishing room was a significant industrial hygiene problem.

2.2.4 Mold and Core Preparation

The primary fugitive emissions problem in the core and mold preparation area is the release of organic vapors from the binders used in heated core box, no-bake, and cold box cores and molds. The major organic binders in use in the United States are shown in Table 2-4. In addition, dust emissions may be produced in the dry mixing of sand and binders.

Shell core-making or shell-molding is a process whereby cores or molds having a thickness of 1/8 to 3/8 in. are produced. These are used for the most

TABLE 2-4. PRINCIPAL ORGANIC CORE BINDERS IN USE IN THE UNITED STATES[17]

Binders	Approximate annual current consumption (lb)	Organic
Oven bake	90×10^6	1. Oleoresinous 2. Urea-formaldehyde resins 3. Phenol-formaldehyde resins 4. Cereal binders
Heated core box		
Shell	85×10^6	1. Phenol-formaldehyde novolaks
Hot box	45×10^6	1. Furan resins (UFFA) 2. Phenol resins (UPF) 3. Phenol-modified resins
Gassed core	3×10^6	1. Cold box (isocyanate)
No-bake	20×10^6	1. Air set (oil-oxygen) 2. Furan no-bake 3. Oil no-bake 4. Urethane (phenolic-isocyanate)

part in applications requiring a great amount of precision. Sand and approximately 5% thermosetting resin (usually having a phenol formaldehyde base) may be dry mixed in a muller.[15,16] The sands may also be prepared by cold, warm, or hot coating. This mix is then blown into a metal box housing the pattern plate, which has been heated to a temperature of 350 to 700°F.[18] The binder within 1/8 to 3/8 in. of the pattern is melted and the material turned into a dough-like substance. Excess sand is dumped off and the shell is then hardened. The primary emissions from the process are CO, formaldehydes, amines, ammonia, and phenols.

Hot box binders are those resins that rapidly polymerize in the presence of acidic chemicals and heat to form a mold or core. The original hot box resins were developed by modifying urea-formaldehyde resins with the addition of 20 to 45% of furfuryl alcohol. This type of hot box resin is commonly referred to as a furan resin. The furan resins were then modified with the addition of phenol to produce urea-phenol-formaldehyde hot box resins, which are referred to as phenolic resins or UPF resins. The UPF resins have a pungent odor and adequate ventilation at the core-making machines is required. More recently, urea-free phenol-formaldehyde-furfuryl alcohol binders have been developed. These have a much lower volatile content and odor compared with other hot box resins as a consequence of eliminating urea from the formulation.[17]

A two-part polyurethane cold box binder system was developed about 1967 that required gassing rather than baking or heating to achieve a cure. Part I of the system is a phenolic resin, and Part II is a polyisocyanate, both dissolved in solvents. In the presence of a catalyst, triethylamine (TEA) or dimethyl ethylamine (DMEA), the hydroxy groups of the liquid phenolic resin combine with the isocyanate groups of the liquid polyisocyanate to form a solid urethane resin which serves as the sand binder. Following introduction of the catalyst into the cold box, air is used to sweep any remaining vapors through the core, after which the core is removed from the core box. The amine catalysts are volatile, flammable, organic liquids and excessive vapors present safety hazards.[17]

The so-called no-bake binders represent modifications of the oleoresious, urea-formaldehyde, phenol-formaldehyde and polyurethane binder systems previously described, in which various chemicals are incorporated to produce polymerization in an unheated core box.[17]

Decomposition products of the various binders are presented in Tables 2-5 and 2-6. It should be noted that these values were obtained by direct venting of prepared cores and are not representative of in-plant ambient levels.

Three other possible sources of emissions in the mold and core area are mulling, molding, and core washing. After castings are removed at the shakeout, the spent sand is returned to the muller where it is mixed with water and

TABLE 2-5. PRODUCTS OF THERMAL DECOMPOSITION OF SAND BINDERS[17]

Product	Threshold limit value (ppm)[b]	Concentration in effluent (ppm by volume)[a]			
		Polyurethane	Oil base	Urea-formaldehyde	Phenolic
Carbon monoxide	50	40,000	40,000	40,000	40,000
Hydrogen cyanide	10	16	400	320	60
Methane	-	2,000	40,000	2,000	2,000
Ethylene	-	1,500	7,000	1,500	1,500
Acetylene	-	1,500	1,500	1,500	1,500
Carbon dioxide	5,000	7,000	11,000	7,000	1,000
Ammonia	25	> 1,500	500	1,500	-
Aldehydes (as formaldehyde)	2	200	> 400	400	> 400
Phenol[c]	5	17.5 mg[d]	0.6 mg[d]	1.5 mg[d]	0.4 mg[d]

a/ All products except phenol were determined in the gas phase. The approximate volumes of the gas phases collected from each binder material were as follows: polyurethane, 200 ml; oil base, 300 ml; urea-formaldehyde, 1,000 ml; phenolic, 200 ml.

b/ Threshold limit values (TLV) established by the American Conference of Governmental and Industrial Hygienists.

c/ Phenol was determined in the condensed liquid phase.

d/ The values given are the total weights of phenol found in the condensed liquid phase.

TABLE 2-6. FUNCTIONAL GROUPS OBSERVED IN INFRARED ABSORPTION SPECTRA OF CONDENSED LIQUID PHASES[a,17]

Functional group	Binder material			
	Polyurethane	Oil base	Urea-formaldehyde	Phenolic
Aliphatic CH	+	+	+	+
Aromatic CH	+	+		+
Ester C=O	+	+		+
COOH		+		
Aldehyde C=O	+		+	
Amide	+			+
Secondary amide		+		
Acidic OH		+		+
Phenyl	+	+		+
Substituted phenyl	+			

a/ The total weights of the condensed liquid phase collected from each binder material were as follows: polyurethane, 120 mg; oil base, 500 mg; urea-formaldehyde, 200 mg; phenolic, 80 mg.

makeup sand and binders. After the sand enters the muller, it is moistened and should present minimal emissions problems. However, transfer of the spent sand to the muller can be a source of particulate emissions.

Sand molding at a foundry is generally accomplished by manually or mechanically packing the sand in the risers. Transfer of material or vibrating of the mold may result in limited quantities of particulate.

After cores have been cured, most are coated with water, alcohol, or naptha-based washes. Common materials included in the wash composition are:[15]

Graphite	Asbestos
Silica	Mica
Talc	Coal
Magnesite	Coke
Alumina	Coal tar
Zircon	Pitch

These washes can be applied through either spraying or dipping. After the wash has been applied, moisture is evaporated by torching in the case of water-based washes and by ignition in the case of naptha or alcohol-based washes. Core washing may be a source of both particulate and organic emissions.

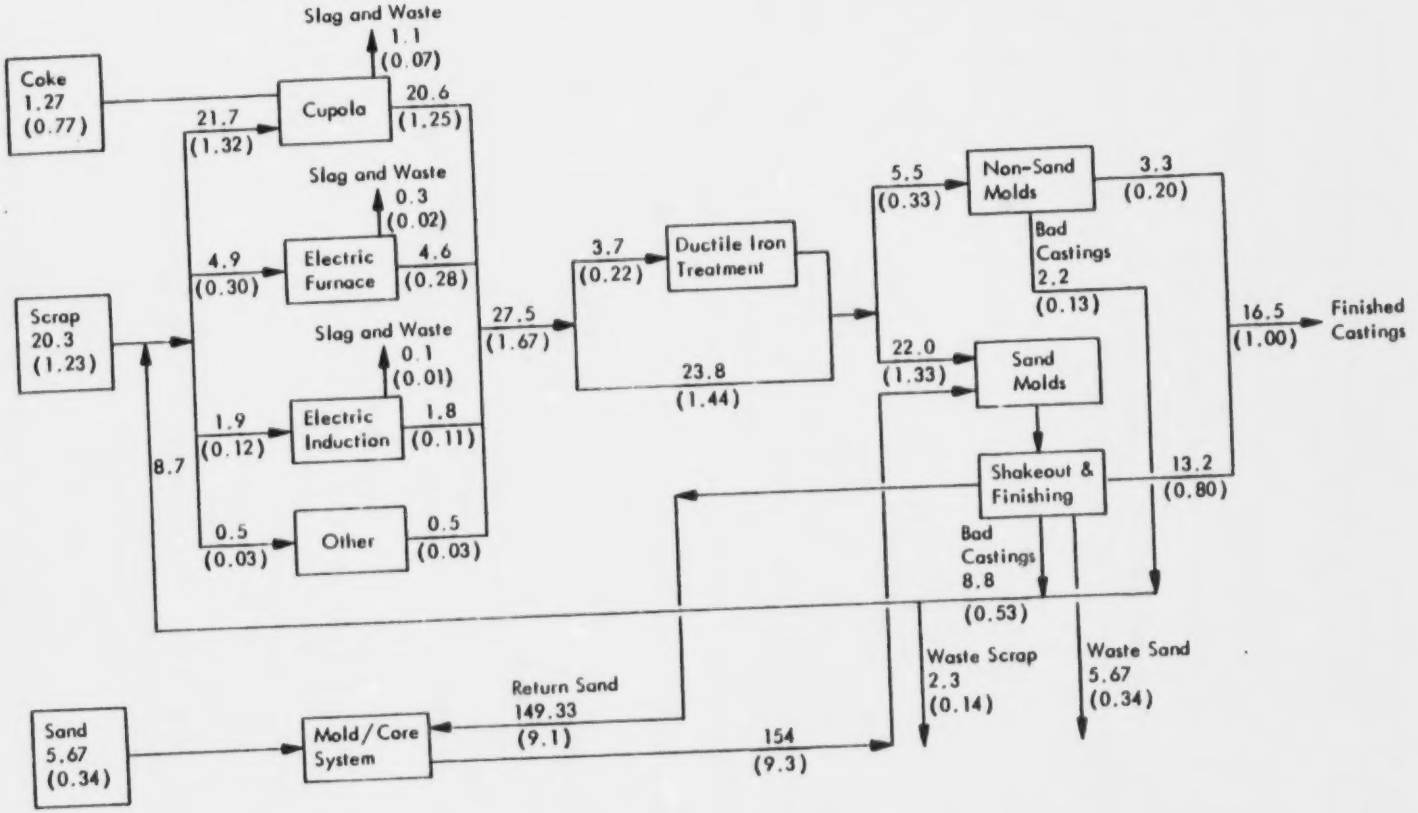
2.2.5 Waste Handling

The primary waste materials produced at a foundry are (a) the slag from the melting operations and (b) spent sand from molds and cores. With each type of melting furnace, the molten metal is transferred to a holding furnace or ladle. The slag rises to the top of the metal and is skimmed off and solidified by air cooling or water quenching. Either cooling method can produce small amounts of SO_2 and H_2S with water quenching producing higher levels.

In foundries using green sand molds, about 2 to 3% of total foundry sand is replaced daily to insure proper sand quality. This sand is generally stored temporarily in either outdoor piles or hoppers. It is then transferred (along with slag) to a landfill for disposal. Potential for dust emissions exists during handling and transfer of the materials to the storage area. If outdoor piles are used, emissions can be generated from wind erosion. Finally, if covered transport vehicles are not used, emissions are generated during the transfer to a landfill for final disposal.

2.3 MATERIALS FLOW

As an aid to determining the relative importance of sources of fugitive emissions in the foundry, an industry-wide materials flow diagram was developed, as shown in Figure 2-8. The materials flows were estimated using 1974 as a base year.



- Numbers indicate annual flows in 10^6 short tons.
- Numbers in parentheses are ratios of material flows to total iron produced.

Figure 2-8. Iron foundry industry weighted material flows.

Scrap consumption in the iron foundry industry was calculated by difference. In 1974, total scrap consumption for cupolas and electric arc furnaces was 53.1 million tons,[19] and scrap consumption in the iron and steel industry was 30.2 million tons,[20] leaving foundry consumption at 22.9 million tons. Assuming iron castings account for 88.8% of foundry production,[19] iron foundry consumption was 20.3 million tons per year.

Reference 19 reported total shipments of 16.5 million tons of gray, ductile and malleable iron in 1974. Information obtained during foundry visits suggests an average yield of 60% good castings. Thus, a total hot metal production of 27.5 million tons was required. Assuming 1.05 tons of scrap are required to produce 1 ton of hot metal, approximately 29.0 million tons of scrap including internal foundry returns were charged to furnaces in iron foundries.

Hot metal production was apportioned among furnaces as follows:

Cupola	74.8%
Electric arc furnace	16.8%
Induction furnace	6.7%
Other	1.7%

Based on ductile iron production of 13.3% in 1974,[19] it was assumed in Figure 2-8 that 13.3% of the hot metal produced was treated.

Both sand and coke inputs were calculated using 1972 Census of Manufacturers data for foundry consumption normalized to 1974 production levels. Total sand throughput was calculated assuming a sand-to-metal ratio of 7:1. It should be noted that the sand throughput value obtained is consistent with the 2 to 5% removal values indicated by industry personnel during plant visits. Finally, the division between sand molds and nonsand molds was assumed to be 4:1, as indicated in Reference 9.

SECTION 3.0

FUGITIVE EMISSIONS QUANTIFICATION

In order to adequately assess the need for control of fugitive emissions in iron foundries, it was essential that estimates of fugitive emissions be developed. In general, compilation of emissions inventories requires emission factors, throughput data, and information on the level of control for each process inventoried. The following subsections of this report (a) discuss the methods by which emission factors are determined and the inaccuracies involved in each of these methods; (b) present and analyze all emission factors developed for the iron foundry industry, and (c) develop an uncontrolled total particulate and fine particulate emissions inventory for major fugitive sources in the foundry industry.

3.1 EMISSION FACTOR QUANTIFICATION METHODS

Usually the first step in conducting any emissions inventory is the determination of emissions factors in units of weight of emissions per weight of process throughput. The units used in this study will be pounds of emissions per short ton of throughput (lb/ton). These values can be converted to kilograms per ton using the conversion factor in Section 8.0. Obviously the best way to accurately determine emission factors is by several repetitions of a highly reliable emissions testing method. However, fugitive emissions testing methods are still in the developmental stages, and only a limited number of fugitive emissions tests have been performed. Hence, it is necessary to estimate emission factors based on stack emissions data and fugitive emissions data from similar processes.

The following two subsections discuss the various fugitive emissions testing methods and those estimating techniques which can be used if test data are not available.

3.1.1 Fugitive Emissions Testing Methods

Three basic strategies for sampling fugitive emissions have been proposed under EPA Contract No. 68-02-1815.[21] These are (a) quasi-stack testing, (b) roof monitor testing, and (c) upwind-downwind testing. Two additional methods which have been examined under the current study are (a) exposure profiling and (b) dilution profiling. Presented below is an analysis of the limitations

of each method with respect to the quantification of iron foundry emissions sources.

Quasi-stack testing requires the hooding or enclosure of the fugitive emissions source in such a manner that complete capture of the fugitive emission stream is achieved. Negative pressure then draws the emission stream through a ducting system where standard stationary source test methods are used to determine emissions. Another version of this method utilizes the capture system on a well-controlled fugitive emissions source. Standard source testing methods are used to determine the emissions by sampling in the ductwork prior to removal of pollutants from the stream by a control device.

The quasi-stack sampling technique has limited application for the foundry industry. The major problems encountered when using the first version of this method are the costs involved in constructing an efficient capture system for anything but small sources and the difficulty of designing a complete capture system which does not interfere with normal foundry operations. The difficulty involved in using installed capture devices to collect samples is that most systems on foundry sources appear to be significantly less than 100% efficient. It may be difficult to locate foundries with capture systems adequate for sampling purposes.

Even if the problems stated above are overcome, two aspects of fugitive emissions may limit the accuracy of the emissions measurements. First of all, many of the fugitive emissions in iron foundries result from the fine particulate nature of materials involved. It is possible that the negative pressure applied at some sources may erode additional fine particulate from the process stream. This will produce an artificially high emission rate for these sources. Also, the accuracy of standard stack sampling methods is partially dependent on a relatively constant emission stream. However, many fugitive sources have a high degree of variation with time. This may lead to inaccurate emission factors if standard methods are used to measure the emission stream.

The roof monitor technique utilizes the natural or forced flow from roof monitors or similar major building exhaust areas to determine total fugitive emissions from a building. This technique uses some pollutant measuring devices such as a hi-vol or gas sampling train and a scanning method (by moving one sampler or by using multiple samplers) to determine an "average" pollutant concentration escaping through the opening. The velocity of the exit gas stream is measured and emissions are calculated.

Roof monitor sampling is best suited for those situations in which a limited number of easily distinguishable operations are conducted in the same building. Foundry operations are such that this is not usually the case. Hence, it is difficult to isolate specific sources for testing. The other major problem in roof monitor sampling is the difficulty in ensuring that the measured

concentrations are in fact the average concentration escaping from the roof monitor and that the measured velocity is representative of the velocity throughout the stream.

Upwind-downwind emissions testing is generally applied to outdoor sources such as roads or storage piles or to estimate emissions from a building or complex of buildings. This technique uses ambient sampling stations upwind and downwind from the source to determine the impact of emissions from the source. A dispersion model is then used to calculate the contribution of the source. Because of the low level of accuracy currently available from most dispersion models, this method is of questionable value if greater than order-of-magnitude accuracy is required. In addition, the method does not have the capability to isolate most fugitive sources within an iron foundry.

The exposure profiling technique is a method which has been developed by MRI for sampling of fugitive dust emissions from roads and storage piles. It is also possible to apply the technique to indoor sources which have an emission stream with a relatively constant convective direction. The method requires a sampler upstream from the emissions source and a grid of isokinetic samplers downstream from the source which completely define the emissions plume. The system has the advantage that it is not dependent upon dispersion models. However, the accuracy of the system is dependent upon constant directional plume which can be isolated from the emission plumes from other sources. These conditions may be difficult to attain for most foundry sources.

As a part of this study, a dilution profiling technique was examined for use on high temperature sources. The basic concept is the same as the exposure profiling technique. However, rather than defining the plume by using a grid of mass samplers, a minimum of two mass samplers are used to determine centerline concentrations and the plume is profiled with temperature sensing devices. The system was tested in laboratory experiments and appear to be a viable means of testing high temperature sources with buoyant plumes. However, it has not been tested on a full-scale operation. The system is limited to those sources which emit a buoyant plume which has a temperature profile significantly higher than ambient temperature.

An analysis of the applicability of the various emissions measurement techniques for major fugitive emission sources in the foundry industry is presented in Table 3-1. The results indicate that only a limited number of tests of fugitive emissions sources have been performed. In addition, little is known about the capability of the various emissions measurement techniques for testing iron foundry fugitive emissions sources with a high level of accuracy. Further work on test methodology, both development and verification, is needed if reliable fugitive emission inventories are to be developed.

TABLE 3-1. ANALYSIS OF FUGITIVE EMISSION MEASUREMENT METHODS

Emissions source	Method applicability				
	Quasi-stack	Roof monitor	Upwind-downwind	Exposure profile	Dilution profile
Raw materials input					
Storage piles	F	F	B	B	F
Coke	F	F	B	B	F
Sand	F	F	B	B	F
Scrap	F	F	B	B	F
Materials handling and transfer					
New sand handling	E	F	E	D	F
Sand screening	E	F	E	D	F
Coke handling	E	F	E	D	F
Melting and casting					
Electric arc furance	D	E	F	E	E
Induction furnace	D	E	F	E	E
Cupola	D	F	F	E	E
Iron inoculation	D	E	F	E	E
Iron pouring	A	E	F	E	E
Casting cooling	C	E	F	E	F
Product finishing					
Shakeout	C	F	F	D	F
Grinding	D	F	F	F	F
Core and mold preparation					
Mulling	D	F	F	F	F
Shellcore or hot box heating	E	F	F	E	E
Shellcore or hot box cooling	E	F	F	E	
Cole set core	E	F	F	E	F
Core wash	D	F	F	E	E
Molding	D	F	F	F	F

(continued)

TABLE 3-1. (continued)

Emissions source	Method applicability				
	Quasi-stack	Roof monitor	Upwind-downwind	Exposure profile	Dilution profile
Waste handling					
Slag quench	F	F	B	D	F
Waste sand transfer	F	F	F	B	F
Sand and slag storage	F	F	B	B	F

Note: A = Has been used to test a full-scale iron foundry operation.
B = Has been used to test a similar operation.
C = Has been used to test process on a bench scale.
D = Has not been used, but should be a viable method.
E = Has not been used; may be a viable method.
F = Not a viable method.

If available test data are insufficient to develop a reliable emission factor, it is necessary to use engineering judgment to develop estimates for these factors. The estimated data presented in this report were generally developed in one of three ways: (a) as a fixed percent of uncontrolled stack emissions, (b) by extrapolation of data for similar processes, and (c) based on input/output data from a process and knowledge of the reactions involved in the process. It should be noted that in all cases where estimated data are used, a relatively low confidence should be placed in these values.

3.2 EMISSION FACTORS FOR THE FOUNDRY INDUSTRY

Available data on iron foundry fugitive emissions were obtained through an extensive literature search, contact with knowledgeable EPA and industry personnel, and comparison of iron foundry operations with similar processes for other industries. It was found that almost no substantive test data are available from full scale foundry operations. Thus, most of the emission factors are engineering estimates based on limited data. Many of the emission factors were derived from information presented by Gutow,[9] Bohn,[22] and Bates.[11,32] There are difficulties involved in the use of the studies in estimating foundry emissions as described below.

Gutow presented emission factors for many of the fugitive sources within iron foundries. The methodology the Gutow used to develop these emission factors was not presented in Reference 9. When further information was requested, the author indicated that the factors were developed as a part of EPA Contract No. CPA 22-69-106, Systems Analysis of Emissions and Emissions Control in the Iron Foundry Industry. However, due to the time span since the completion of the study in 1971, it is no longer possible to access the original data or methodology.

Bohn, et al., developed emission factor equations for materials handling operations in integrated iron and steel plants. These equations are based on a limited number of exposure profiling tests at integrated iron and steel plants. These operations differ from those in iron foundries with respect to both size and location. However, since no test data are available for foundry materials handling, the equations were used to estimate emission factors. But, the reliability of these emission factors is questionable.

Bates and Scott have determined emissions from several foundry sources through the use of quasi-stack sampling. However, each of the tests was conducted on a bench or pilot scale operation, rather than a full-scale process in an operating foundry. It is not possible to ascertain the effect of scale on these emissions. Hence, the reliability of the emission factors developed from these data is uncertain.

Even though the data obtained from the sources described above and similar sources are of questionable reliability, they are the best available data. Hence, these data were used to develop the emission factors in the following sections.

3.2.1 Raw Materials Storage and Handling

No test data are available for materials handling operations in foundries. Hence, data from Gutow[9] and Bohn, et al.[22] are used to estimate emission factors.

Gutow[9] gives an emission factor of 12.3 lb/ton of melt for emissions from dry sand handling, prepared sand handling and drying, and sand reclamation. However, 90% of these emissions are greater than 50 μm in diameter and are likely to fall out in the foundry. Hence, only 10% or 1.2 lb/ton melt of sand handling emissions escape to the atmosphere.

Gutow[9] also presents an emission factor of 10 lb/ton of melt for sand screening, again with 90% of the particles greater than 50 μm in diameter. Thus, the emission factor is 1.0 lb/ton of melt for particulate escaping to the atmosphere.

Based on these data from Gutow, total emissions from return sand handling and screening is estimated to be 2.2 lb/ton of melt, the total of the above two values. Since the sand-to-metal ratio is on the average 7:1, this represents 0.3 lb/ton of sand handled.

Based on data from tests on operations at integrated iron and steel plants, the emission factor equations presented in Figures 3-1 through 3-3 were developed for particulate emissions from loading of materials onto storage piles and wind erosion from the piles. The emission factor equations were derived for particles smaller than 30 μm in Stokes diameter. The quality assurance rating scheme for the emission factors is shown in Figure 3-4. The paragraphs below present the estimates of particulate emissions from storage and handling of sand, coke, and scrap that were derived from the equations.

As indicated in Section 2.2.1, sand is usually stored in enclosed bins and is often transported pneumatically. If closed storage and transport are utilized, the emissions from the system will be negligible. If conveyors are used to transfer sand to storage and from storage to the mold and core preparation area, emissions of particulate less than 30 μm are estimated to be 0.04 lb/ton of sand transferred for each transfer point.

The emission factor for conveyor transfer of sand to storage was calculated using the equation for conveyor transfer to storage presented in Figure 3-1. Since the transfer is conducted inside a building, the correction factor for wind speed was disregarded. The silt content was assumed to be 7% based on specifications received during a plant visit.[23] Sand purchased by foundries is generally cleaned and dried; hence, a low moisture content of 0.5% was assumed.

OPEN DUST SOURCE: Storage Pile Formation by Means of Translating Conveyor Stacker

QA RATING: B

$$EF = 0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)}{\left(\frac{M}{2}\right)^2} \text{ lb/ton}$$

Determined by profiling of emissions from pile stacking of pelletized and lump iron ore.

where: EF = suspended particulate emissions (lb/ton of material transferred)
s = silt content of aggregate (%)
M = moisture content of aggregate (%)
U = mean wind speed (mph)

Figure 3-1. Predictive emission factor equation for storage pile formations by means of translating conveyor stacker.[22]

OPEN DUST SOURCE: Transfer of Aggregate from Loader to Truck
QA RATING: B

$$EF = 0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)}{\left(\frac{M}{2}\right)^2\left(\frac{Y}{6}\right)} \text{ lb/ton}$$

Determined by profiling of emissions from load-out of crushed steel slag and crushed limestone.

where: EF = suspended particulate emissions (lb/ton of material transferred)
s = silt content of aggregate (%)
M = moisture content of aggregate (%)
U = mean wind speed (mph)
Y = effective loader capacity (yd^3)

Figure 3-2. Predictive emission factor equation for transfer of aggregate from front-end loader to truck.[22]

OPEN DUST SOURCE: Wind Erosion from Storage Piles
QA RATING: C

$$EF = 0.05 \left(\frac{s}{1.5}\right)\left(\frac{D}{90}\right)\left(\frac{d}{235}\right)\left(\frac{f}{15}\right) \text{ lb/ton}$$

Based on upwind/downwind sampling of emissions from inactive storage piles of sand and gravel.

Estimated factors to correct measured emissions to other source conditions.

where: EF = suspended particulate emissions (lb/ton of material put through storage cycle)
s = silt content of aggregate (%)
D = duration of storage (days)
d = dry days per year
f = percentage of time wind speed exceeds 12 mph

Figure 3-3. Predictive emission factor equation for wind erosion from storage piles.[22]

QUALITY ASSURANCE RATING SCHEME

A = FORMULATION BASED ON STATISTICALLY REPRESENTATIVE NUMBER OF ACCURATE FIELD MEASUREMENTS (EMISSIONS, METEOROLOGY AND PROCESS DATA) SPANNING EXPECTED PARAMETER RANGES

B = FORMULATION BASED ON LIMITED NUMBER OF ACCURATE FIELD MEASUREMENTS

C = FORMULATION OR SPECIFIC VALUE BASED ON LIMITED NUMBER OF MEASUREMENTS OF UNDETERMINED ACCURACY

— OR —

EXTRAPOLATION OF B-RATED DATA FROM SIMILAR PROCESSES

D = ESTIMATE MADE BY KNOWLEDGEABLE PERSONNEL

E = ASSUMED VALUE

Figure 3-4. Quality assurance (QA) rating scheme for emission factors.[22/]

No test data are available on sand handling in iron foundries. The equation in Figure 3-1 was used to develop an emission factor of 0.04 lb/ton of sand per transfer point for particulates less than 30 μm as described above. In addition, Vandegrift et al. developed a sand handling emission factor of 0.3 lb/ton of sand; however, neither the method of determination nor the operations covered by the factor were identified.[24]

A diagram of a sand handling system at one foundry is shown in Figure 3-5.[25] It appears that after the shakeout there are a minimum of 10 transfer points plus a separator, aerator, and drum sand cooler. If the equation from Figure 3-1 is used with the values for silt and moisture content given earlier, total emissions from the transfer operations of the return sand are calculated to be 0.4 lb/ton of sand. Emissions from the screening and cooling are visually estimated to be equivalent to transfer operations. Hence, total emissions from the return sand system are estimated to be 1 lb/ton sand. However, many of these emissions are controlled by hooding systems, and thus actual emissions may be much lower.

No data are available on emissions from the handling and storage of foundry coke, nor are data available on silt content or moisture content of the coke. It was assumed that the values of 1% silt content and 1% moisture developed in Reference 22 for metallurgical coke are appropriate for foundry coke. (Based on the similarity in the production process of these cokes, this assumption appears to be reasonable.) Using these assumptions, an emission factor of 0.0014 lb/ton of coke per conveyor transfer point was calculated using the equation from Figure 3-1. Thus, load-in and load-out of storage piles is estimated to have an emission factor of 0.003 lb/ton.

If a high loader is used to transfer coke, the equation from Figure 3-2 can be used to calculate an emission factor of 0.0005 lb/ton coke dumped. Finally, if coke is stored in outdoor storage, wind erosion emissions are calculated to be 0.02 lb/ton coke using the equation in Figure 3-3. This assumes the average storage duration to be 60 days and assumes the default values apply for dry days and percentage of the time that wind erosion exceeds 12 mph. Thus, total coke storage emissions are at most 0.03 lb/ton which are negligible compared to other operations.

The amount of emissions from scrap storage is directly dependent on the amount of dirt contained in the scrap; for well-cleaned scrap, emissions will be negligible. If we assumed as worst conditions 5% dirt in the scrap and a storage time of 60 days, an emission factor of 0.1 lb/ton scrap can be estimated for wind erosion from scrap piles. Data are insufficient to estimate emissions from transfer of scrap.

The emission factors developed above were based on limited data, and several assumptions used to calculate the factors. Hence, low reliability (QA level D or E) should be placed on the emission factors for sand, coke, and scrap storage and handling.

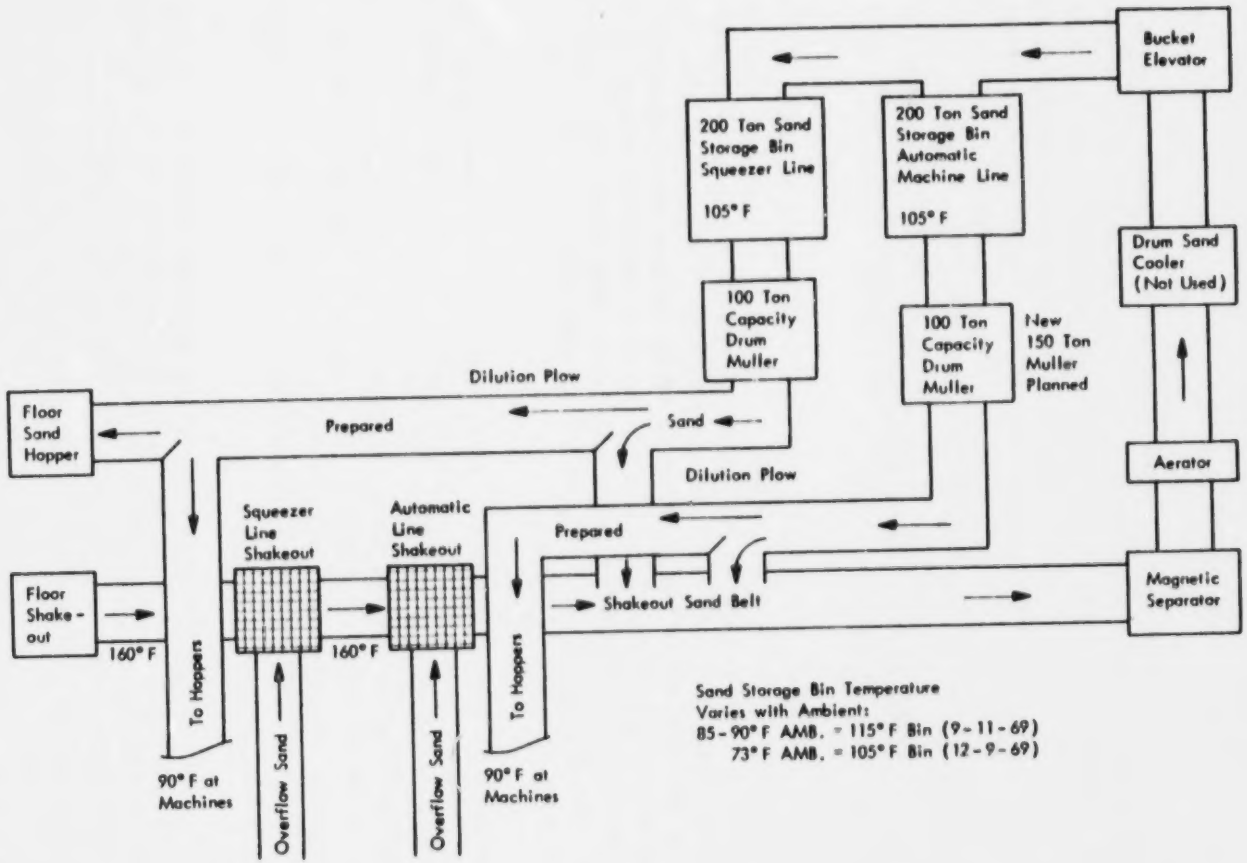


Figure 3-5. Line drawing of Canton Malleable's sand system showing plowoff points and resultant sand temperatures.[25]

3.2.2 Melting and Casting

3.2.2.1 Electric Arc Furnace--

Data in the literature indicate that total emissions from electric arc furnace melting range from 3.0 to 40.0 lb/ton of charge, with an average emission factor of 13.8 lb/ton.[26] The manufacturer of an efficient close capture hooding system has indicated that total baghouse catch for emissions from all stages of an EAF at foundries charging dirty and oily scrap is on the order of 35 to 40 lb/ton of charge.[27] Based on visual observation, it is claimed that the hooding system captures most of the emissions from the EAF from charging through tapping. If it is assumed that the baghouse captures 99+% of the emissions, then the total uncontrolled particulate emissions from that facility are slightly more than 35 to 40 lb/ton of metal charged.

The level of fugitive emissions from an EAF is dependent on the capture effectiveness of the primary system and the cleanliness of the scrap charged. If no primary control system is used, total emissions are fugitive and are estimated to be in the range of 4 to 40 lb/ton of metal charged. If, as is the typical case, a fourth-hole duct or side draft hood is used to capture melting emissions, 5 to 10% of total emissions are estimated to be fugitive. Thus, an emission factor of 0.5 to 3.0 lb/ton of charge with an average of 2.0 lb/ton is estimated for typical EAFs. Again, this is based on limited data and is considered to have relatively low reliability.

3.2.2.2 Electric Induction Furnaces--

Reference 28 indicates that electric induction furnaces have a total emission factor of 1.5 lb/ton charge. Since these furnaces generally have no capture system, the total was assumed to be the effective fugitive emission rate.

3.2.2.3 Cupola Tapping--

Based on visual observations during plant visits, cupola tapping appears to be a source of fugitive particulate emissions. However, no data are available to determine the extent of these emissions.

3.2.2.4 Iron Inoculation--

An engineering estimate of emissions from inoculation can be developed from mass balances of the magnesium used for inoculation. Data from Reference 29 indicate that the amount of magnesium added to inoculate iron will vary from 0.12 to 0.30% of the iron treated, or from about 2.4 to 6.0 lb of magnesium per ton of iron. About 1.3 lb of magnesium are consumed in reaction leaving about 1.1 to 4.7 lb of magnesium per ton of iron. This will react to form 2 to 8 lb of MgO, which is emitted to the atmosphere. Since MgO accounts for only 60 to 80% of the emissions from iron inoculation,[29] the fugitive emission rate may range from about 2.5 to 13 lb/ton of iron inoculated.

Test data from an inoculating station indicate an emission rate of 3.3 lb/ton of iron inoculated for an operation similar to the one described above.[30] For this station, a total of 20 to 22 lb of inoculant, comprised of soda ash, MgFeSi (10% Mg), and 75% Fe, were used per ton of iron. Only 32% of the emissions produced were MgO. In this case, it appears that about 70% of the magnesium was retained in the iron. Huelson[31] indicates that with current practices 50 to 90% of the magnesium is expected to be retained in the iron.

Based on these data, 0.4 to 2 lb of MgO will be formed for each ton of iron treated. Assuming the quantity of other particulate emissions to be constant at about 2 lb/ton, an emission rate range of 2.4 to 4.0 lb/ton with a typical value of 2.5 lb/ton is estimated.

3.2.2.5 Pouring and Cooling--

The most significant testing data for foundry fugitive emissions have been generated for the iron pouring and cooling operations. A series of quasi-stack emissions tests was conducted on actual pouring operations in an iron foundry.[21] The data from these tests yielded emissions factors for iron pouring ranging from 0.55 to 4.5 lb/ton of metal poured. However, difficulties were encountered in this test in separating background particulate from emissions.

In another study [11] quasi-stack tests were run on both bench-scale and pilot-scale pouring and cooling operations. The pouring and cooling of a 30-lb cube casting resulted in a total of 54.61 g of particulate,[32] which gives an emission rate of 8.3 lb/ton. Based upon concentration profile data, this has been separated into 4.0 lb/ton for pouring and 4.3 lb/ton for cooling.[33] Data on concentrations of organic gases evolved during pouring and cooling are also presented. However, data are insufficient to determine emission factors.

Gutow[9] has also developed emission factors for iron pouring and cooling. The emission factor given for pouring is 5.10 lb/ton of melt with 60% of the particles greater than 50 μm. Hence, the factor for emissions escaping to the atmosphere is 2.0 lb/ton of melt. The cooling emission factor is 10.30 lb/ton of melt with 90% of the particles being greater than 50 μm. The emission which escape to the atmosphere are 1.0 lb/ton.

3.2.3 Product Finishing

The only major sources of fugitive emissions in the product finishing area are shakeout and grinding. As a part of the testing discussed earlier, Bates and Scott used the quasi-stack to develop an emission factor of 3.15 lb/ton of cast iron with 98% of the mass less than 15 μm in diameter.[32] Gutow estimated an emission factor of 32.20 lb/ton melt with 90% of the particles being greater than 50 μm in diameter. Hence, the emission rate is 3.2 lb/ton for those particles escaping to the atmosphere.

Data are insufficient to determine an emission factor for grinding.

3.2.4 Core and Mold-Making

The only data available for core and mold-making are presented by Gutow.[9] He indicates that mulling has an emission rate of 20.60 lb/ton of melt with 90% of the particles greater than 50 μm. It is assumed that particles larger than 50 μm will not reach the atmosphere. Thus, emission rate is 2.1 lb/ton melt. This factor seems high but no other data are available.

According to Gutow, molding has an emission rate of 0.50 lb/ton melt with 90% having diameter greater than 50 μm.[9] Hence, the effective emission rate (those particles less than 50 μm) is 0.05 lb/ton melt.

Based on observations during plant visits and conversations with industry personnel, particulate emissions from shell-core and mold and cold set processes appear to be negligible. Data are insufficient to determine emissions from core washing.

3.2.5 Waste Handling

Since no data are available on emissions from waste handling in the foundry industry, the following estimates were developed based on equations in Ref. 22. Based on a silt content of 7% (see Section 3.2.1) and an average storage period of 90 days before covering, sand storage emissions are estimated to be 0.24 lb/ton. Based on the assumption that foundry slag storage emissions are comparable to iron and steel slag storage, an emission factor of 0.18 lb/ton slag stored[34] is estimated. Data are insufficient to estimate emissions from slag quenching.

3.3 INVENTORY OF IRON FOUNDRY EMISSIONS

The data on production rates presented in Section 2.3 and the best emission factors from Section 3.2 were used to generate an inventory of fugitive emissions from iron foundries. This inventory is presented in Table 3-2. The third column presents the total annual particulate emissions from each source. It should be noted that some of the values are for particulate of less than 30 or less than 50 μm in diameter and some are for TSP. This is a result of the variation in the reporting practice in the literature and the fact that particle size data are insufficient to translate the values to a common basis.

In addition, estimates of the fine particle content (particles less than 5 m in diameter) were estimated and a fine particle inventory developed. These data are presented in the last two columns of Table 3-2.

It is again stressed that the emission factors used in this table are based on very limited data and as such have a low reliability. Consequently this emission inventory should be applied with caution.

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TABLE 3-2. FUGITIVE PARTICULATE EMISSIONS INVENTORY

Emission Source	Estimated Emission Factor	Process Rate (ton/yr)	Annual Emissions (lb/yr)	Fine Particle (< 5 m)	Fine Particle Emissions (lb/yr)
Raw Materials Input					
Storage	Neg	-	-	-	-
Coke	Neg	-	-	-	-
Sand	0.1 lb/ton scrap	4.0×10^7	2.0×10^6	30[a]	6.0×10^5
Scrap					
Handling and Transfer	Neg	-	-	-	-
New Sand	2.2 lb/ton melt	2.7×10^7	5.9×10^7	30[a]	1.8×10^7
Spent Sand	0.2 lb/ton coke	1.3×10^6	2.6×10^5	30[a]	7.8×10^4
Coke					
Melting and Casting	No Data	-	-	-	-
Cupola Tapping					
EAF Charging, Tapping, Leakage	2.0 lb/ton charge	4.9×10^6	9.8×10^6	80[b]	7.8×10^6
Induction Furnace	1.6 lb/ton charge	1.9×10^6	2.8×10^6	80[b]	2.2×10^6
Inoculation	2.5 lb/ton inoculated	1.7×10^6	4.2×10^6	80[b]	7.4×10^6
Pouring	4.0 lb/ton poured	2.2×10^7	8.8×10^7	99[a]	8.4×10^7
Cooling	4.2 lb/ton poured	2.2×10^7	9.5×10^7	99[a]	9.0×10^7
Finishing	3.15 lb/ton cast	2.2×10^7	6.93×10^7	50[a]	3.5×10^7
Shakeout	No Data	-	-	-	-
Grinding					
Mold and Core Preparation	2.1 lb/ton melt	2.7×10^7	5.7×10^7	30[a]	1.7×10^7
Molding					
Shell or Hot Box	No Data	-	-	-	-
Heating	No Data	-	-	-	-
Holding Pallet	No Data	-	-	-	-
Coldset	No Data	-	-	0	-
Core Wash	0.05 lb/ton melt	2.7×10^7	1.4×10^6	30[a]	4.2×10^5
Molding					
Waste Handling	No Data	-	-	-	-
Slag Quench	0.3 lb/ton sand	4.7×10^6	1.7×10^6	30[a]	5.1×10^5
Waste Sand Transfer					
Storage	0.24 lb/ton sand	5.7×10^6	1.4×10^6	30[a]	4.2×10^5
Sand	0.18 lb/ton slag	1.5×10^6	2.7×10^5	30[a]	8.1×10^4
Slag					

[a] Estimated based on previous materials handling emissions tests.

[b] Assumed same as electric arc furnace.

SECTION 4.0

FUGITIVE EMISSIONS CONTROL

As a result of the internal plant environmental problems created by fugitive emissions sources in iron foundries, effective control methods have been developed for many of these sources. These control methods may be separated into the following three basic components:

1. Preventive process and operating changes.

2. Capture methods for containment of the fugitive emissions stream.

3. Devices for removal of pollutants from the captured emission streams.

Preventive process and operating changes act to control fugitive emissions by either eliminating or reducing emissions at the source. These preventive measures may consist of minor changes in operating procedures, such as wetting of dusts on storage piles, or better monitoring of input materials to ensure more consistent feed properties. Increased maintenance and more efficient use of existing equipment can also lead to decreased emissions. Finally, basic redesign of equipment or processes may be practicable, especially in new or remodeled plants.

When preventive measures are not practicable, fugitive emissions must first be captured by a hood and ducting system or by containment within a closed building or special enclosure with a venting system. Three types of hoods may be considered: (a) fixed, standard-type hoods and ducts (such as standard laboratory hoods), (b) portable hoods with flexible ducts (such as those used currently in some machining and pilot-plant processing areas), and (c) custom hoods with moving closures (such as those used on copper converters).

The removal devices for fugitive emissions are similar to those used for primary confined source emissions. These devices must be used in conjunction with a capture or collection method and blower to capture and force the emission stream through the removal device. Thus, a total fugitive emission control system must include capture and collection methods and one or more removal devices. For example, particulate emissions from a high-temperature fugitive source might be captured by a hood and duct with a blower, the large particulates removed by a cyclone separator, the carrier gases cooled in an exhaust

gas cooler pipe, and the fine particulates removed by a baghouse. The optimum choices of removal devices depend on the types of emissions, the size distribution of the particulate emissions and the properties of the carrier gases.

For some sources, the fugitive emissions may be ducted directly back into the emission control system for the primary source. However, if large amounts of air are required to capture and collect the fugitive emission in a hood or enclosure, then the concentration of emissions (gases or particulate) may be much lower than for the primary source. This decrease in concentration must be considered in evaluation and selection of potential removal devices.

As indicated earlier, control systems have been developed for many of the major sources in the foundry industry. A summary of possible control systems for these sources is presented in Table 4-1. Also included in Table 4-1 are estimates of the effectiveness of the various abatement, capture and removal methods and an indication of some problems associated with the application of some of the methods.

To the extent that source operations vary from plant to plant, it is unlikely that a single control option would be most suitable for uniform application throughout the industry. Added to this is the need for determining the degree to which individual fugitive sources at a given plant are to be controlled in order to meet plant-specific control strategy objectives. The most cost-effective control strategy for a particular plant entails the application of the most efficient controls to the largest contributing sources.

In the sections below, control system options are presented for the following fugitive source categories:

1. Raw material input

    - Coke and scrap piles
    - New sand handling
    - Coke handling
    - Spent sand handling

2. Melting and casting

    - Cupola tapping
    - Electric arc furnaces (leakage, charging, and tapping)
    - Electric induction furnaces
    - Iron inoculation
    - Pouring and cooling

3. Finishing

    - Shakeout
    - Grinding

TABLE 4-1. FUGITIVE EMISSIONS CONTROL TECHNOLOGY SUMMARY

Fugitive emissions source	Capture or abatement system			Removal system		
	Method	Effectiveness	Problems	Method	Effectiveness	Problems
Raw material input						
Storage						
Coke	Enclosed storage	99%	None	-	-	-
Sand						
Scrap						
Handling and transfer				-	-	-
New sand handling	Pneumatic transfer	100%	None	Wet scrubber	99% +	None
	Covered belts and enclosed transfer	Good	None	Baghouse	99% +	None
Coke handling	Hooded screens	Good	None	Wet scrubber	99% +	None
				Baghouse	99% +	None
	Enclosed transfer and covered belts	Good	None	Wet scrubber	99% +	None
				Baghouse	99% +	None
Spent sand handling	Covered belts and enclosed transfer	Good	None	Wet scrubber	99% +	None
	Schumacher process	99% +	Some capital investment	-	-	-
Melting and casting						
Cupola tapping	Stationary hood	DI	Interference with operations	Primary capture system	90%	May have excessive fine particles
	Moveable hood	DI		Primary capture system	90%	
Electric arc furnace	Canopy hood	DI	Capture problems with cross draft, high flows	Baghouse	99%	Costs high due to large volumes
	Closed charging system	DI	Requires sized scrap, does not control tapping	Baghouse	99%	No data
	Hooded charging bucket	DI	Does not control tapping	Main melting system	-	No data
	Furnace enclosure	DI	Interference with operation	Baghouse	99%	No data
	Close capture hooding	60-85%	None	Baghouse	99%	No data
Induction furnace	Close capture hooding	90-95%	None	Baghouse	99%	No data
Iron inoculation	Tapping hood	DI	May interfere with melting operations or impossible to interface	Main melting system	99%	No data
	Booth	DI	May be safety hazard	Baghouse	-	-
Iron pouring				DI	-	-
Floor pouring	Building evacuation	DI	High cost	DI	-	-
	Mobile vent	DI	Questionable effectiveness	DI	-	-
Pouring station	Pouring hood	Good	None			
Iron cooling				DI	-	-
Floor pouring	Building evacuation	DI	High cost	DI	-	-
Pouring station	Mold funnel	Good	None			

(continued)

TABLE 4-1. (continued)

Fugitive emissions source	Capture or abatement system			Removal system		
	Method	Effectiveness	Problems	Method	Effectiveness	Problems
Product finishing						
Vibrating shakeout	Total enclosure	Good	None	Wet scrubber	98-99%	None
	Side draft hood	Moderate	None	Wet scrubber	98-99%	None
Revolving shakeout	Enclosure	DI	None	Wet scrubber	98-99%	None
Grinding	Swing grinder booth	DI	None	Wet scrubber	99% +	None
				Baghouse	99% +	None
	Downdraft table	DI	Size limitations	Wet scrubber	99% +	None
Core and mold preparation						
Mulling	Hooded charging	Good	None	Wet scrubber	99% +	None
Shellcore or hot box						
Heating	Overhead hood	DI	May be ineffective	Chemical scrubber	90-100%	None
Holding pallet	Moveable hood	DI		Chemical scrubber	90-100%	None
Cold set	Closed system	DI		Chemical scrubber	90-100%	None
Core wash	Spray booth	DI	May be a safety hazard during torching	DI	-	-
Molding	None needed	-	-	-	-	-
Waste handling						
Slag quench	DI	-	-	DI	-	-
Waste sand transfer	Wetting	90-95%	-	-	-	-
Storage piles	Wetting	DI	-	-	-	-

Note: DI = Data insufficient.

4. Core and mold preparation

   - Mulling
   - Shell or hot box heating
   - Shell or hot box cooling
   - Cold set preparation
   - Core wash
   - Molding

5. Waste material handling

   - Slag quench
   - Waste sand transfer
   - Slag and sand storage

For each of the above source categories, control options (including both emissions capture methods and pollutant removal methods) are presented. Process changes which act to limit or eliminate emissions are also considered as control options. For each control method, equipment operating parameters, expected level of performance, associated operational problems, and estimated capital and operating costs are given when available.

4.1 RAW MATERIALS INPUT

This section describes the preventive measures and control systems that can be used to limit fugitive particulate emissions from raw material handling and preparation. Those sources examined include coke and scrap storage piles, new sand handling, spent sand handling, sand reclaimers, and coke handling. With the exception of some storage operations, most of these sources are currently controlled within the foundry industry.

4.1.1 Material Storage

As indicated in Section 2.2.1, the only possibly significant emissions from material storage occur in the outdoor storage of coke and scrap. No data are available on measures which can reduce emissions from outdoor storage without degradation of materials. It appears that the only practicable measure to control storage emissions is the use of an enclosed storage area. No data are available on cost of enclosures. However, many foundries now have covered storage to avoid degradation of coke and scrap.

4.1.2 Materials Handling

Fugitive emissions problems from handling of raw materials have been divided into three basic areas: (a) new sand handling and storage; (b) coke handling; and (c) spent sand handling and reclamation. Controls for each of these areas are described in the following subsections.

4.1.2.1 New Sand Handling--

As new sand is received at the foundry, it is transferred to storage bins by pneumatic feed or mechanical conveyor. The pneumatic system is totally enclosed and in effect is well-controlled. However, with mechanical systems, further controls are necessary.

In most foundries visited by MRI personnel, sand handling conveyors appeared to be adequately controlled. Reference 37 suggests that the following ventilation system is adequate to control dust emissions.

At transfer points with less than a 3-ft drop, the transfer point should be enclosed and air should be exhausted from the top of the enclosure at the rate of 350 cfm/ft of belt width for belt speeds less than 200 fpm. An exhaust rate of 500 cfm/ft of belt width should be used for belts with speeds in excess of 200 fpm. If the drop is greater than 3 ft, an additional exhaust should be used at the lower level with a flow rate of 700 cfm for 12- to 36-in. belts and 1,000 cfm for belts wider than 36 in.

Belts should also be covered between transfer points with additional exhaust points at 30-ft intervals. Exhaust rates of 350 cfm/ft of belt width are sufficient to control dust emissions between transfer points.

Huelsen[35] has indicated that wet scrubbers (6- to 10-in. pressure drop) are normally used to remove particulate from sand handling ventilation systems. In addition, fabric filters for removal were observed at several plants visited by MRI. These systems appeared totally effective in capturing and removing particulates at the plants visited by MRI. Reference 36 indicates that particulate removal efficiency for the scrubber is 99+%.

4.1.2.2 Coke Handling--

Coke is generally transferred manually or mechanically within the foundry. Little can be done to control the negligible emissions from manual handling. With mechanical conveyors the systems described in Section 4.1.2.1 should be effective in controlling emissions.

At some foundries coke is screened before going to the cupola to eliminate fines which may have been created. The following control measures are recommended for use with screening devices.

Fugitive dust emissions from vibrating screens can generally be captured in an overhead hood. Particulate can then be removed from the emissions stream by either a scrubber (6- to 10-in. pressure drop) for humid or dry emissions streams or by baghouses for dry streams.[35]

A typical hooding system for a vibrating screen is shown in Figure 4-1. Reference 37 suggests that a flow rate of 70 cfm/sq ft of screen area is needed for adequate capture emissions. It has been estimated by MRI that capture efficiencies of 75 to 90% can be attained with this system.

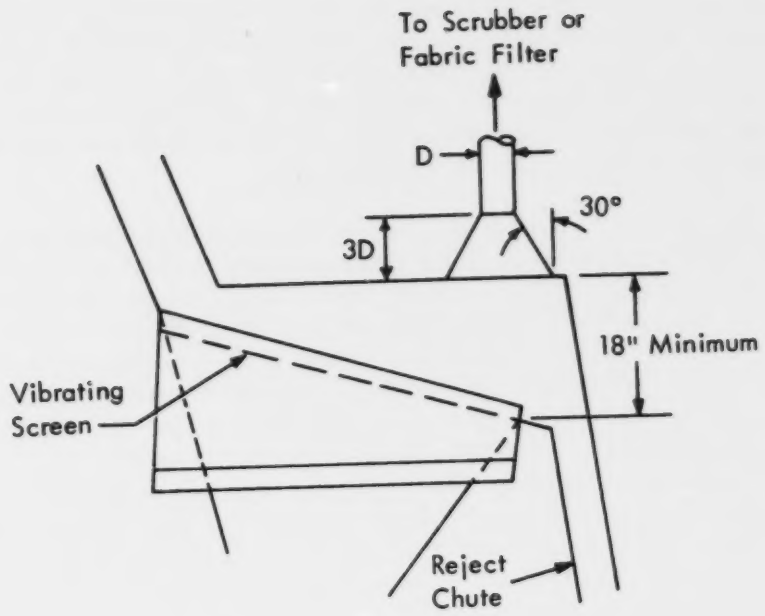


Figure 4-1. Hooding system for a vibrating screen.[37]

For control of fugitive dust emissions from rotating drum screening operations, hoods enclosing the drum as completely as possible should be utilized. A typical system is shown in Figure 4-2. Reference 37 suggests that a flow rate of 125 cfm/sq ft of cross-sectional area of the screen should be used. In cases where removal of large quantities of fines is necessary, 150 cfm/sq ft should be used. The particulate removal devices for these systems are the same as those described for vibrating screens and removal efficiencies are of the same magnitude.

4.1.2.3 Spent Sand Handling--

After the sand leaves the shakeout, it is dry and has potential for high levels of fugitive emissions during transfer and reclamation. If mechanical conveyors are used, it is essential that the controls described in Section 4.1.2.1 be utilized. No data were obtained which described systems for controlling emissions from sand reclaimers. However, based upon observations during plant visits it appears that a system such as that described for vibrating conveyors will adequately control reclaimer emissions.

A patented concept (U.S. Patent No. 3,461,941) has been developed which has the potential for control of fugitive dust emissions from most sand handling operations other than shakeout. The process is called the Schumacher Sand Process System. The normal sand-to-metal ratio in a green sand foundry is between 5 and 7:1. The Schumacher process utilizes a sand processed to metal ratio of 20:1. This is the quantity of sand put through the muller. However, the extra sand is not utilized to produce molds. It is diverted to an inundator. Here the hot dry sand taken off the shakeout is mixed with the moist sand from the muller to produce a moist cool sand. This sand is then taken through the normal sand handling processes. However, the now moist sand presents no emissions problems. Tests near transfer stations indicate that dust concentrations are reduced by as much as 99% by application of the system.[38]

The system requires little additional equipment (the inundator and a small amount of additional mulling equipment) and is estimated to cost substantially less than equivalent collection systems. The system is claimed to have the additional advantages of saving binder loss and producing cooler sand for the molding line.

4.2 MELTING AND CASTING

The operations that occur in an iron foundry from the time scrap is charged into a furnace for melting until the time the casting is to be removed from the mold constitute the greatest fugitive emission sources for which generally applicable control measures have not been found. The primary control problems from melting are (a) cupola tapping, (b) electric arc furnace charging, tapping, and leakage, and (c) induction furnace charging. Other major emission sources in this area include (a) inoculation of ductile iron, (b) pouring hot metal into molds, and (c) cooling the filled molds before shakeout. Possible fugitive emissions control methods for these sources are discussed below.

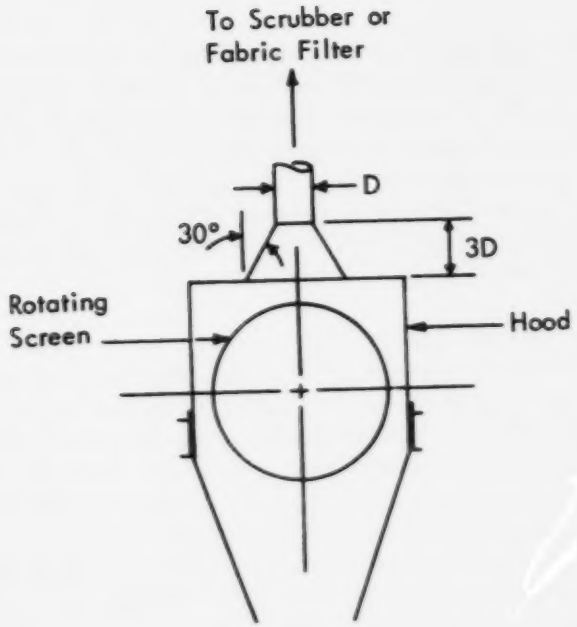


Figure 4-2. Hooding system for revolving screen.[37]

4.2.1 Cupola Tapping

In general, the tapping of hot metal from any melting furnace, and in particular from a cupola, appears to be one of the lesser sources of fugitive emissions in the melting and casting areas. However, control of these emissions may be necessary on new plants located in regions with high ambient particulate levels, or in plants melting scrap containing significant amounts of hazardous metals.

Limited data are available on capture methods for particulate emissions from cupola tapping. A local exhaust hood such as that shown in Figure 4-3 is suggested in Reference 39 for cupolas having toxic fumes. A velocity of 150 ft/min through the hood opening is suggested. If this type of permanent system is utilized, it will be necessary to use a rail arrangement to move the ladle to the cupola's spout. It is suggested that new systems be designed in such a way that this system can be vented to the removal device used for primary control of cupola emissions.

When a permanent system described above is not feasible, a movable system such as that shown in Figure 4-4 is suggested. In this system, a telescoping duct with a funnel-type hood is suspended near the cupola. An additional hood, which is joined with the funnel hood on the duct, is attached to the ladle. This system has the advantage that the ladle can remain attached to the crane during tapping, which is more efficient from a standpoint of time. The disadvantage is that the hood is located a greater distance from the ladle, making it more difficult to capture emissions. It is suggested that these emissions be vented to the primary removal device. It should be noted that particulate emissions from tapping may be in the submicron size range. If this is the case, the primary removal device would possibly not be effective and alternative control measures may be necessary.

No data are available on flow rates necessary for efficient performance of the movable hood system. Cost data are not available on either the fixed or the movable system.

4.2.2 Electric Arc Furnaces

The use of electric arc furnaces (EAFs) for scrap melting is expanding rapidly, especially in high production foundries. The most serious fugitive emissions problem associated with EAFs is the charging of scrap, particularly dirty or oily scrap. Thus, the methods chosen for fugitive emissions capture should first address the charging problem. The system used for tapping and leakage emissions should then be interfaced with the charging and primary melting emissions capture systems.

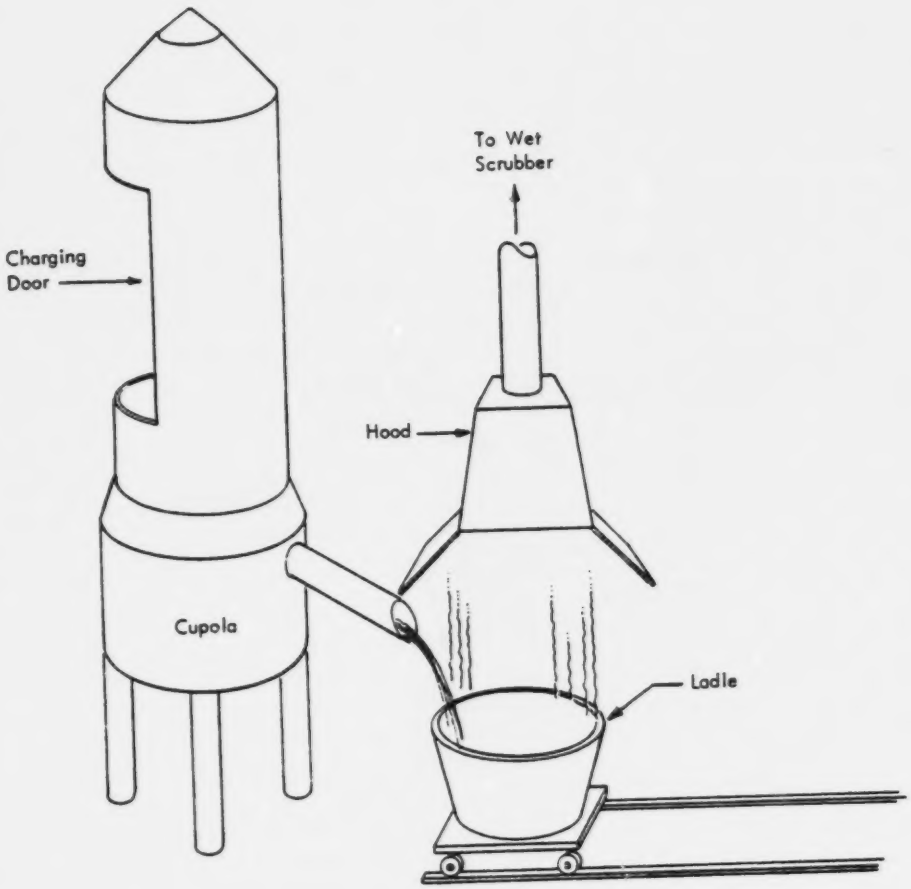


Figure 4-3. Fixed hood for cupola tapping.[39/]

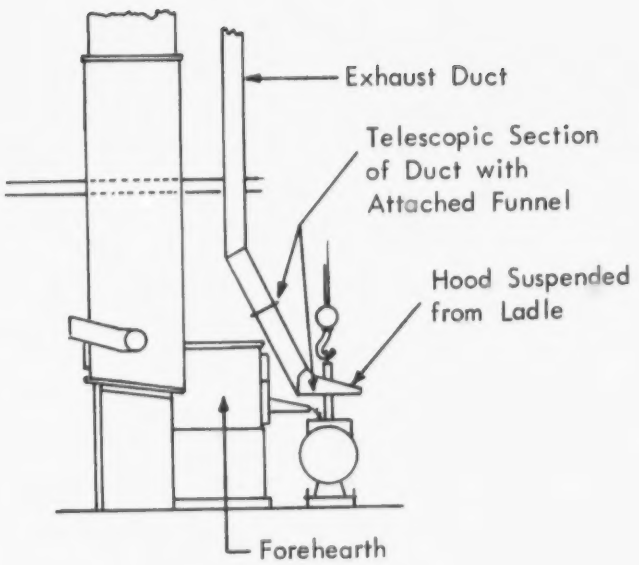


Figure 4-4. Movable hood for cupola tapping.[39/]

Over the past several years many attempts have been made to design systems which can adequately control EAF charging emissions. The following five general types of systems can be utilized to capture charging emissions:

1. Canopy hooding
2. Closed charging systems
3. Hooding charging buckets
4. Total furnace enclosures
5. Close hooding

The type of system chosen for a particular EAF may vary depending on such parameters as building design, size of furnace, necessary degree of control and whether the system is for new or existing furnaces. The closed charging system and the close hooding system are discussed below. The other systems are discussed fully in Reference 22.

4.2.2.1 Closed Charging System--

One conceptual method for control of EAF charging emissions which has not been applied commercially utilizes an automated charging system that does not require removal of the furnace hood. This system uses the primary melting emissions control system as a capture device, eliminating the need for another capturing system. However, a major disadvantage of the system is that it requires sized scrap with diameter less than 3 in., which may increase system cost excessively. Since no systems of this type are currently operating, data on cost and effectiveness of the system are not available.

4.2.2.2 Close Capture Hooding System--

Hawley Manufacturing Corporation has patented a close capture hooding system for electric arc furnaces which controls emissions during charging, melting, slagging, and tapping operations. The system (shown in Figure 4-5) uses a large plenum (mixing chamber) connected to four separate hoods and a removal device by movable ductwork to allow continuous exhaust during all phases of furnace operation. The four hoods are positioned (a) around the electrodes for control during meltdown, (b) over the tapping spout, (c) around the slag door for control during slagging or oxygen lancing, and (d) suspended off the side of a movable hood for control during charging. Each of the hoods is automatically controlled to allow ventilation to be directed toward the area of greatest emissions. Typically, 30 to 35% of the total flow is to the slag hood during all phases of the operation. During charging and meltdown the other 70 to 75% of the flow is directed to the charging hood and electrode hood, respectively. During tapping 25% of the flow is directed to the electrode hood and the remaining 45 to 50% to the tapping spout.[40]

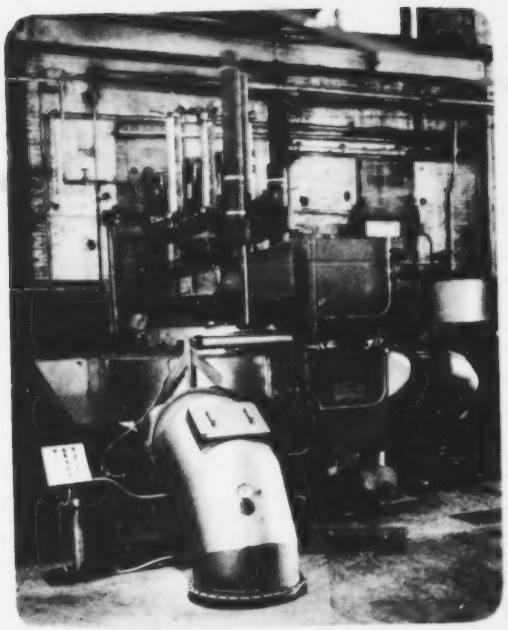


Figure 4-5. Close capture hooding system for electric arc furnaces.

The system, called the TOT-L-VENT system, has been installed on EAFs ranging in size from 6.0 to 12.0 ft in diameter. Furnaces in this size require air volumes ranging from 20,000 to 35,000 acfm.[40] The parameters affecting the required flow are: (a) furnace shell diameter, (b) transformer rating, (c) nominal heat size, (d) oil content in charge, (e) charge composition, (f) rate of oxygen lance, (g) size of charge bucket, and (h) size of ladle.[41] The cost for a capture system of this size range is on the order of $20,000 to $30,000. This cost includes all engineering design, manufacturing, electrical control panel and installation of the capture system. It does not include removal device costs.

Capture efficiencies on the order of 90 to 95% for tapping, 60 to 90% during charging and 99% (no visible emissions) during melting can be expected from the system. Normally capture efficiency is on the order of 80 to 90%. However, on some systems design difficulties and charging of extremely dirty scrap have led to lower capture efficiencies.[40]

The removal system suggested by the manufacturer is a shaker-type fabric filter with an air-to-cloth ratio of 2:1 and no more than 3:1. The pressure drop across the system is 14 in., 6 in. in the hooding device and the remainder in the baghouse and blower.[41]

Similar systems were suggested by other manufacturers but no specific data were obtained.

4.2.3 Electric Induction Furnace

Electric induction furnaces have fewer emissions than other types of melting equipment. Hence, in the past induction furnaces have often had no pollution control. A close capture hooding system such as the one shown in Figure 4-6 is suggested for control of induction furnace emissions during charging, tapping, and melting. This close capture system is patented by Hawley Manufacturing Company. Other manufacturers suggested that they do supply similar hoods on a custom basis. However, no specific data were provided.

The hood is built into the furnace platform and has a telescopic duct to allow the hood to move with the furnace and to maintain flow during tapping. The top of the hood and one side swivel away from the furnace to allow access to the furnace during charging. The hood is normally used with a system of hoods for two or three furnaces attached to a common removal device. This allows the user to take advantage of the different flows required for charging and melting. Required flow rates for various size furnaces are:[40]

1. Less than 15 tons	7,500 cfm for charging 2,000 cfm for melting
2. 15 tons to 50 tons	20,000 cfm for charging 5,000 cfm for melting

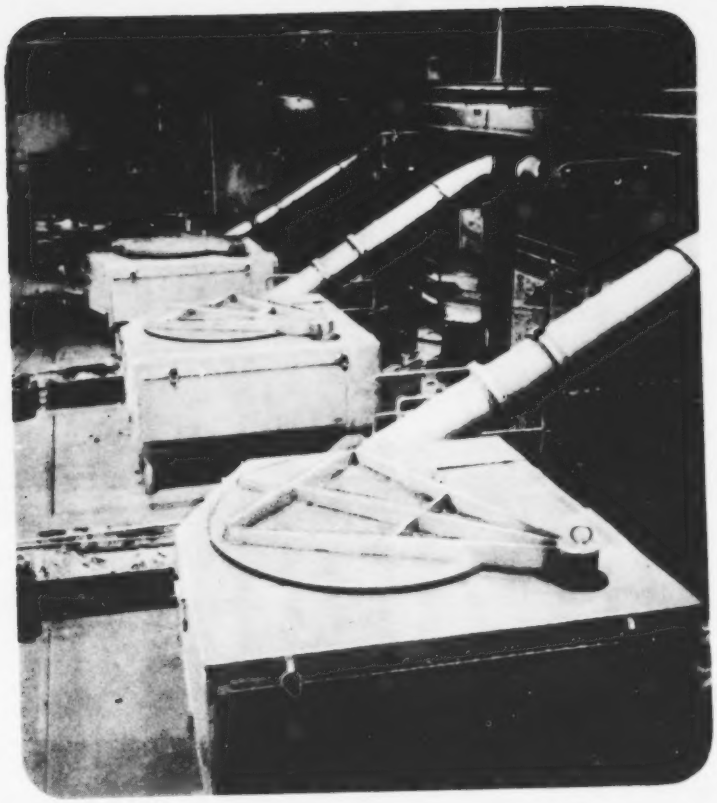


Figure 4-6. Close capture hooding system for electric induction furnace.

3. 40 tons to 50 tons	25,000 cfm for charging 5,000 cfm for melting

One plant engineer indicated that no visible emissions had been observed during either charging or melting on three 5-ton induction furnaces.[42]

The suggested removal device is a shaker-type fabric filter with an air-to-cloth ratio of 2.1:1 and not more than 3:1. The pressure drop across the hood is about 4 in. of water with a 6-in. drop across the baghouse.

4.2.4 Iron Inoculation

Approximately 15% of the iron castings produced in the United States utilize ductile iron. Generally, ductile iron is produced by the addition of magnesium or other alloying substances to molten iron after it has been tapped into the ladle. The primary methods of capture for iron inoculation emissions are (a) utilization of the furnace tapping control system, and (b) use of separate enclosures for iron inoculation. If operations permit, the most efficient method to control iron inoculation is to add the alloying agents while the ladle is still in place from tapping. In this instance, the tapping control system can be used for control of iron inoculation.

If furnace operations do not permit inoculation at the tapping station, a separate enclosure, such as that shown in Figure 4-7 is suggested. Air curtains or door at the roof opening for the crane may be utilized to prevent escape of the buoyant emissions. A velocity of 100 to 125 fpm should be maintained at each opening. A fabric filter is suggested for pollutant removal.

The authors are unaware of any commercial system such as that described above. Hence, no substantive data on cost or efficiency of the system are available.

As described in Section 2.2.2.4, emissions from iron inoculation are dependent upon the process chosen for inoculation. By the application of techniques which yield high magnesium capture efficiency, it is possible that emissions may be reduced to the extent that add-on control measures are unnecessary. However, data are not sufficient to substantiate this view.

4.2.5 Iron Pouring and Cooling

The mold pouring and cooling floor has been one of the dirtiest and most difficult areas to control in the iron foundry. Much of the difficulty in developing economically feasible controls has arisen from the variation of pouring methods from foundry to foundry and from the large areas over which emissions occur in a particular foundry. In fact, Huelsen[35] has indicated that some foundries cannot absorb the cost of controlling these sources. While this may be true for small foundries, several alternatives appear to be feasible for larger foundries, especially new foundries.

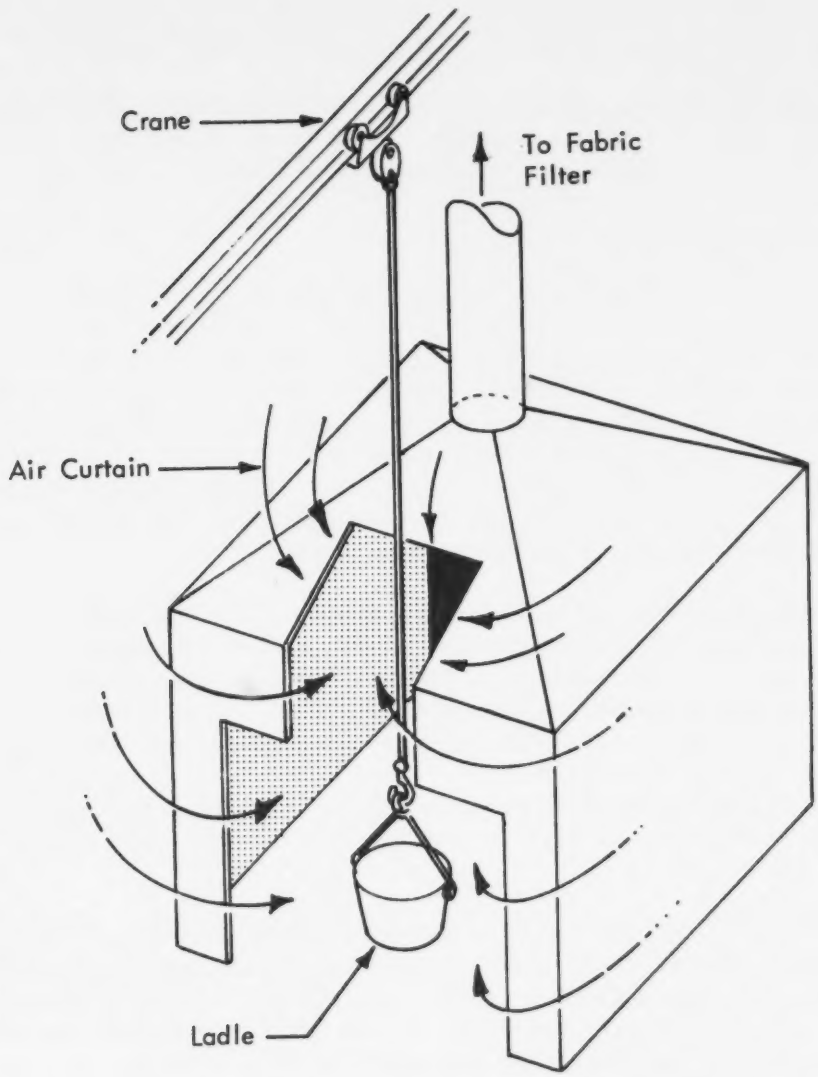


Figure 4-7. Enclosure for ladle inoculation.

Three types of control measures appear to be technically viable. For new or redesigned foundries which produce many copies of the same castings, "permanent" or reusable metal or graphite molds can be used in place of green sand molds to reduce emissions. A second alternative is the use of a stationary hooded pouring station in conjunction with an enclosed cooling conveyor. Finally, for those foundries in which the mold is placed on the floor and the ladle is moved to the mold, some type of movable hooding system or building evacuation will be required. Each of these systems is discussed in the following paragraphs.

4.2.5.1 Permanent Mold Casting--

The standard process for production of gray iron castings has utilized green sand molds with sand cores bound by organic binders. For many years "permanent" or reusable molds have been used to produce small cast iron parts. However, recent developments have made it possible to extend the process to other high volume castings.[43]

The permanent mold-casting technique uses reusable molds of iron, steel or graphite which are held together by a machine. The mold is coated with an insulating material and cores are set into place. After the hot metal is poured into the mold and allowed to solidify, the mold is opened. The maximum time from the beginning of a pour until the mold is released is about 3 min.

Tests of emissions from 13-lb cast iron blocks produced from a permanent mold and a green sand mold were reported in Reference 43. The results of these tests are given in Table 4-2. The permanent mold technique resulted in a 99% reduction in particulate emissions and a 99% reduction in hydrocarbon emissions. If capture of the remaining pollutant is deemed necessary, the stationary mold machines are relatively easy to hood. The technique has the additional advantage of reducing emissions in the sand handling and core-making areas and virtually eliminating shakeout problems.

The cost analysis in Reference 43 indicated that production costs would be equal to or slightly less than costs incurred with conventional high volume molding processes. Cost reductions were estimated to be $0.005 to $0.015/lb for gray iron and $0.02/lb for ductile iron. This did not include adjustment for the reduced capital cost obtained from elimination of much of the sand handling and storage equipment. Hence, for a new high volume foundry, permanent mold-casting methods appear to be a viable alternative to sand mold casting.

It should be noted that this method can be economically applied only in those foundries producing adequate volume of identical castings. Reference 44 suggests that a minimum of 2,000 castings per mold is required to make this system competitive with green sand molding. In addition, this control method is more appropriate for new or significantly modified foundries than for foundries currently in operation with adequate process equipment. Finally, it has been suggested that there may be size limitation in the use of the process.

TABLE 4-2. COMPARISON OF EMISSIONS FROM GREEN SAND AND PERMANENT MOLD PROCESSES FOR PRODUCING A 13-LB UNCORED CASTING UNDER VENTILATED CONDITIONS[43]

	Green sand (S:M ratio = 7:1)	Permanent mold
Time of emissions	1 hr	3 min
Dust loading	0.04052 gr/scf	0.01017 gr/scf
Calculated total weight of particulate evolved on a one-casting basis	5.5 g	0.15 g
Maximum hydrocarbon concentration	1,800 ppm	125 ppm
Average hydrocarbon concentration	460 ppm	100 ppm
Maximum carbon monoxide concentration	1,350 ppm	100 ppm
Average carbon monoxide concentration	250 ppm	> 50 ppm

4.2.5.2 Mold Pouring Hood/Conveyor System--

If green sand molds are used, the best method of control consists of stationary hooded pouring stations and covered conveyors for mold cooling. Reference 39 suggests that the hot metal be placed in the ladle and then be covered with a steel lid to limit emissions during transport. The ladle is then transported to a hooded pouring area such as that shown in Figure 4-8. The molds are moved through the pouring area on a conveyor and, upon leaving the pouring area, are transported through a mold tunnel such as that shown in Figure 4-9 to shakeout. Commercially available models of these systems are described in References 45 and 46.

Reference 37 suggests a flow rate of about 150 to 175 cfm/linear foot of hood with slot velocities of 1,500 fpm for the pouring hood. Exhaust takeoffs every 8 to 10 ft are recommended. The enclosed smoke hood for the conveyor will require about 75 to 100 cfm/linear foot of hooding with a minimum flow of 200 fpm through all openings. Exhaust takeoffs should be located on approximately 60-ft centers.

One manufacturer indicates that the velocity through control areas for the pouring hood will generally be in the range of 150 to 200 ft/min.[47] The system has an air supply system to properly distribute flows across open areas. Hood lengths range from 10 to 200 ft. Most pouring hoods are 50 to 70 ft long. Exhaust connections to the plenum are on approximately 20-ft centers and supply connections are usually midway between the exhaust connections.[46]

Significant numbers of the installation described above have been installed in the United States. The installed cost of these systems in 1977 range from about 60 to 80¢/cfm of exhausted air. Although no data on capture effectiveness are available, manufacturers representatives indicate that visually, capture appears essentially complete.

No data have been obtained on the type of removal devices to be used for pouring and cooling. However, the moist nature of the emissions stream seems to indicate that wet scrubbers (probably high pressure drop) would be the most suitable type of system. However, information from industry personnel indicates that scrubbers are not sufficient to control these emissions. A secondary scrubber such as that described in Section 4.4 may be necessary to control the hydrocarbon emissions generated during pouring and cooling. No data are available on the efficiency and cost of this system.

4.2.5.3 Portable Exhaust Hoods--

For those pouring operations where a stationary pouring area is not feasible, the most efficient solution appears to be a portable exhaust hood attached to the pouring ladle (see Figure 4-10). Reference 39 suggests that this exhaust system can be used with either monorail or crane and can capture emissions with a flow of 1,500 cfm/ladle. A scrubber (probably medium or high pressure drop) is suggested as the most appropriate removal device, possibly with a secondary device to remove hydrocarbon emissions as described in Section 4.4.

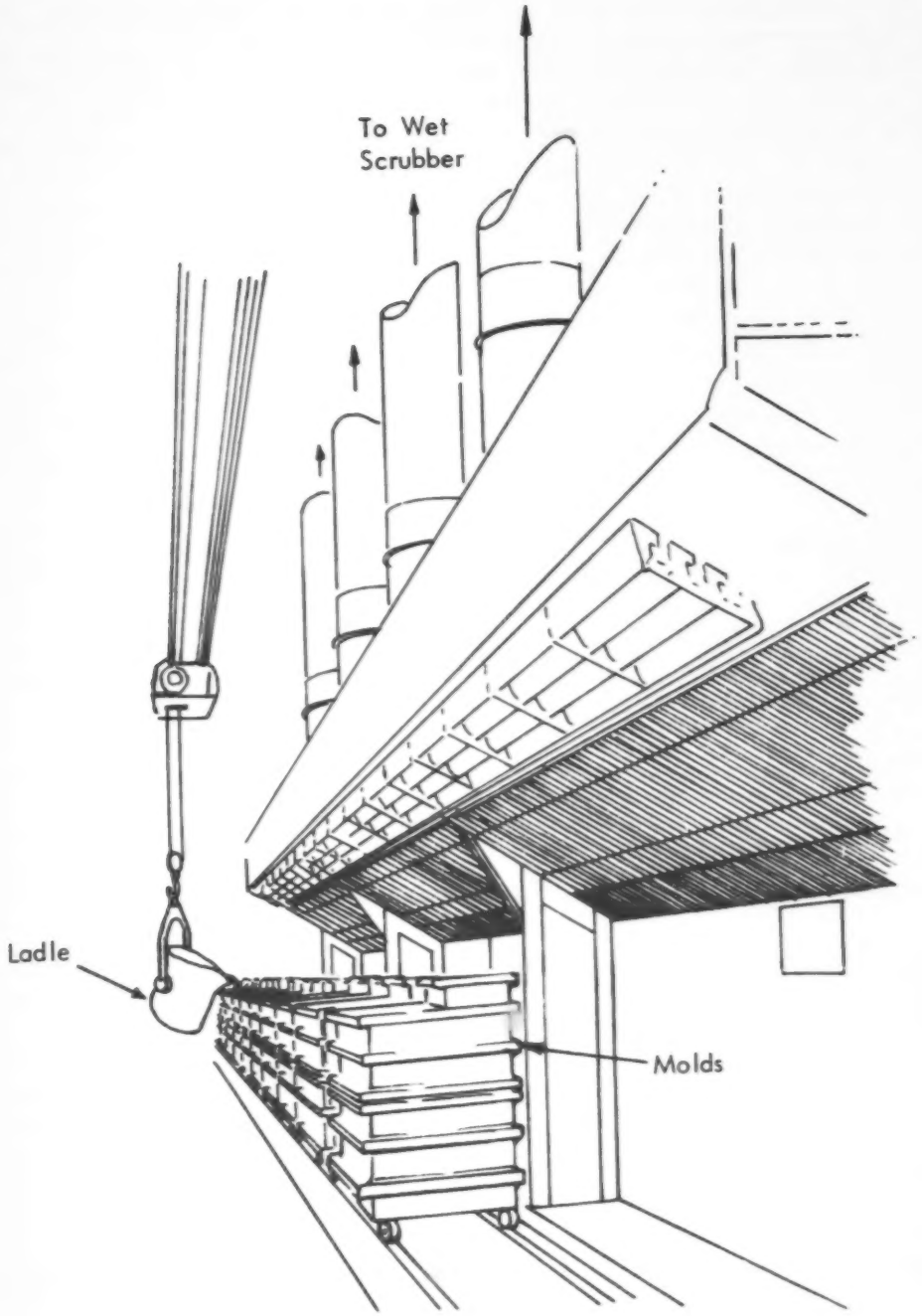


Figure 4-8. Hooded pouring station.[46/]

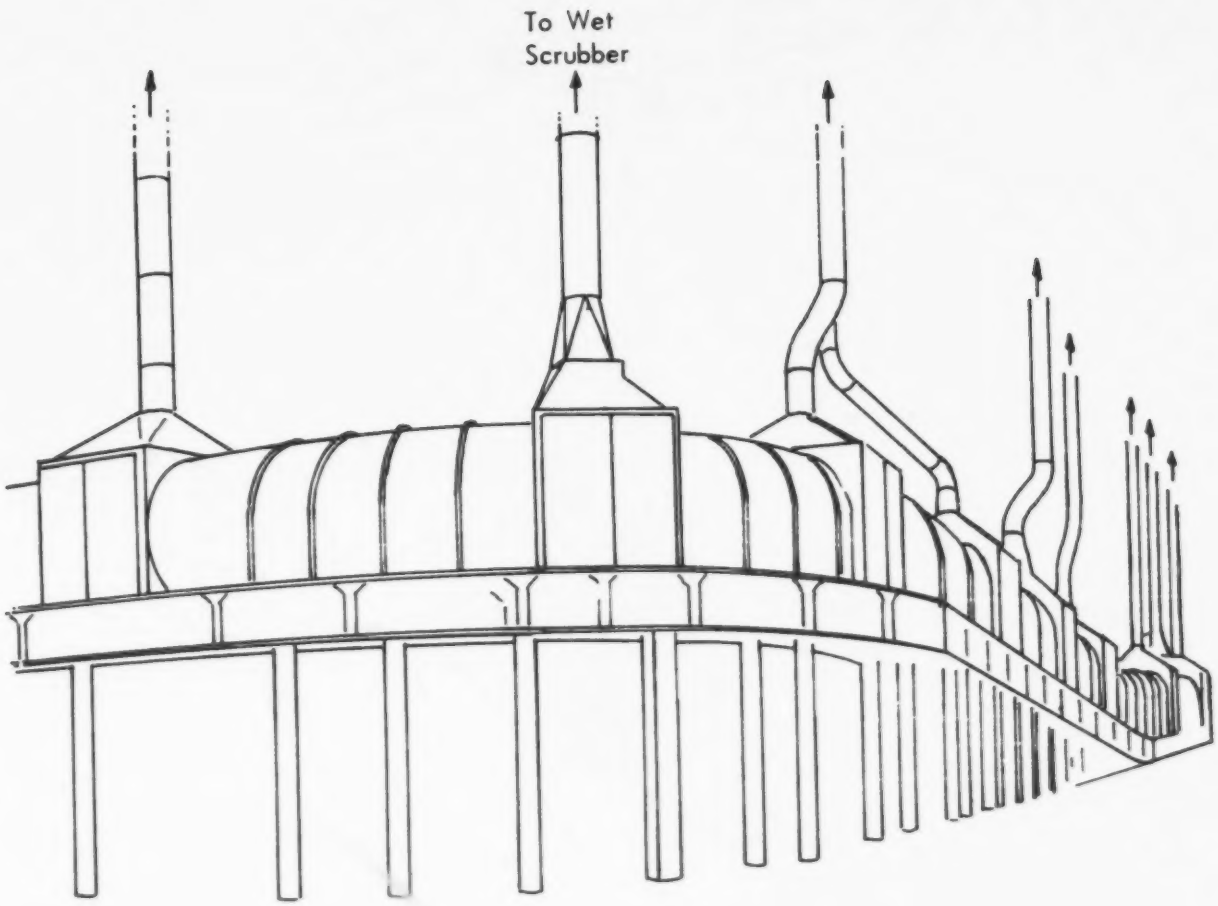


Figure 4-9. Mold tunnel.[46/]

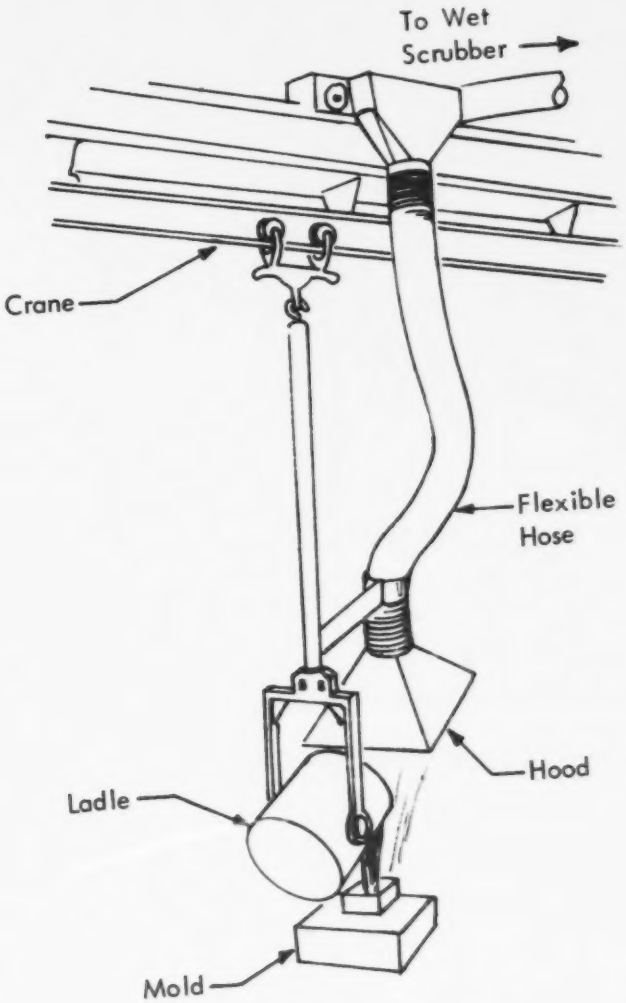


Figure 4-10. Movable pouring hood.

The primary disadvantage of this system is that it provides for no control of emissions during cooling. There appears to be no effective capture system other than building evacuation for cooling emissions if stationary molds and movable ladles are used. No data on operating parameters or costs are available for building evacuation.

4.3 PRODUCT FINISHING

Castings can be removed from a sand molding: (a) mechanically removing the casting from the mold with a fork or payloader, (b) vibrating shakeout, or (c) revolving shakeout. The latter two are of primary interest from a control standpoint. Grinding may also be significant in a fugitive emissions control problem.

4.3.1 Casting Shakeout

In the foundry, removal of the casting from the sand mold has traditionally been accomplished by placing the mold and casting on a heavy vibrating screen. This causes the sand to be shaken from the casting and dropped onto a conveyor where it is returned for reuse. Recently, however, a revolving shakeout system has been developed which may lead to easier control of dust emissions. The following subsections describe possible control measures for each of these sources.

4.3.1.1 Vibrating Shakeout--

As described above, the shakeout operation in foundries has generally consisted of a vibrating screen which shakes the sand from the casting. The mold is generally placed on the shakeout by either an overhead crane, manual placement or by conveyor. The capture method used is dependent on the operation. The three most common methods are a type of side draft, double side draft (or push and pull), overhead hood (generally used with crane or manual placement) or a complete tunnel enclosure of the shakeout (generally used with conveyor systems).

Reference 15 describes the side draft hood for shakeout shown in Figure 4-11. For shakeouts less than 6 ft wide, a flow rate of 500 cfm/sq ft of shakeout grate is recommended. It is also suggested that sufficient air be exhausted from the shakeout hopper to provide a downdraft of 40 ft/min through the grate. For shakeouts greater than 6 ft in width, hoods should be used on any two adjacent sides with a flow rate of 500 cfm/sq ft of grate area. It is suggested that flow rates need to be increased if (a) castings are quite hot, (b) sand-to-metal ratio is low, or (c) cross drafts are high.[15] However, no data are provided as to effectiveness of higher flow rates under the above conditions. A wet scrubber (1- to 10-in. pressure drop) is suggested as the best particulate removal device for this system, due to the moisture level of gases from shakeout. Reference 48 indicates that 90% effectiveness can be attained with proper side draft hooding. If we assume a grain loading of 0.5 to 1.0 gr/cu ft[48] and attain the outlet loading of 0.01 gr/scf suggested by Reference 35, this yields

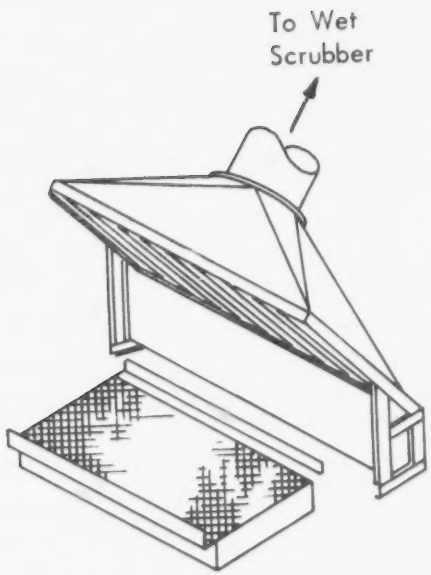


Figure 4-11. Side draft hooding for vibrating shakeout.[15/]

a scrubber efficiency of 98 to 99%. Thus, total collection efficiency is in the range of 88 to 89%.

When operations permit, an enclosed tunnel system is suggested. Reference 46 suggests for similar sources that an air velocity of 105 ft/min through the openings should be maintained. Reference 48 suggests that a total flow of 15,000 to 30,000 cfm is needed. It may be possible to acquire part of this velocity through the use of air curtains at openings. As with the sidedraft hood, a wet scrubber is suggested as removal device. With the enclosed hood, collection efficiencies on the order of 97% can be expected.[48] With lower grain loadings of 1 to 3 gr/scf due to increased air flow, removal efficiencies of 99+% can be attained.[36] Thus, a total collection efficiency of 96% can be obtained.

4.3.1.2 Rotary Shakeout--

A recent development in the foundry industry is the rotary shakeout pictured in Figure 4-12. This system is described in Reference 49. Since no specific data on control systems have been found, a removal system similar to that described for revolving screens (Section 2.2.2) is suggested. Reference 49 suggests that air flows on the order of 2,000 to 4,500 cfm are adequate for dust control. Since shakeout exhaust gases have a high moisture content, a wet scrubber is suggested as the best removal device. This device claims to be advantageous because of a decreased level of emissions due to less turbulence. However, it is limited to small to medium sized castings.

4.3.2 Grinding

As indicated in Section 3.4.2 four basic types of grinders are used in foundries: bench grinders, floor stand grinders, portable grinders, and swing grinders. In general, most grinding operations are controlled with the type of control dependent upon the type of grinder and casting and other possible operations which may have interfacing control devices. Many control operations are custom designed so data on generally applicable systems are limited. Those systems for which data were obtained are described below.

Reference 50 suggests that emissions from a swing frame grinder are best controlled by an exhaust hood such as that shown in Figure 4-13. A control air volume of 100 cfm/sq ft of opening is minimum and 150 cfm/sq ft of opening is preferred. Reference 36 suggests that grinding emissions can be adequately removed (99+% efficiency) with either a wet scrubber (6- to 30-in. pressure drop) or a fabric filter. No data on the cost or effectiveness of these systems were obtained.

For bench and some portable grinding operations, self-contained capture and removal systems such as the one shown in Figure 4-14 are available. At least one manufacturer has systems capable of handling up to a 10,000-lb load.[51] General flow rates are on the order of 300 ft/min downdraft through the grating. No details on cost or effectiveness of the system were obtained.

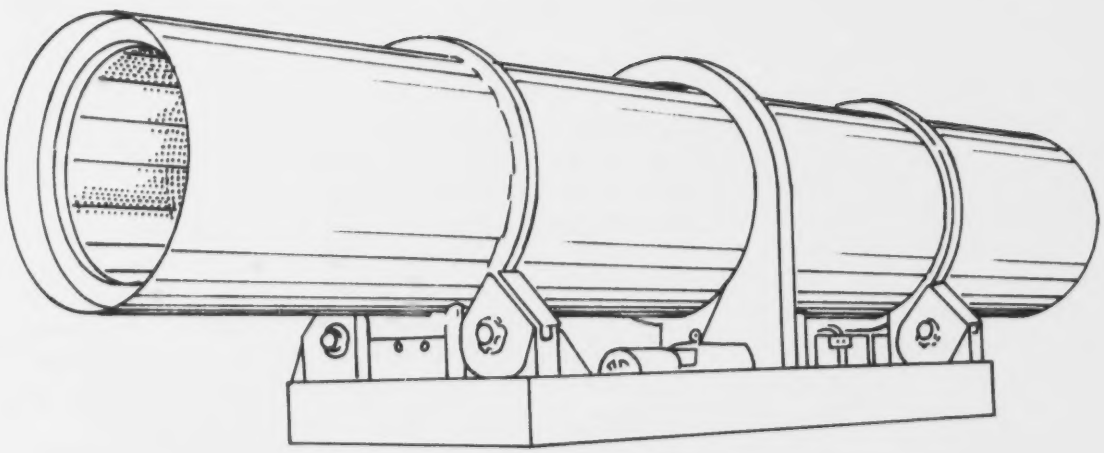


Figure 4-12. Rotary shakeout.[49/]

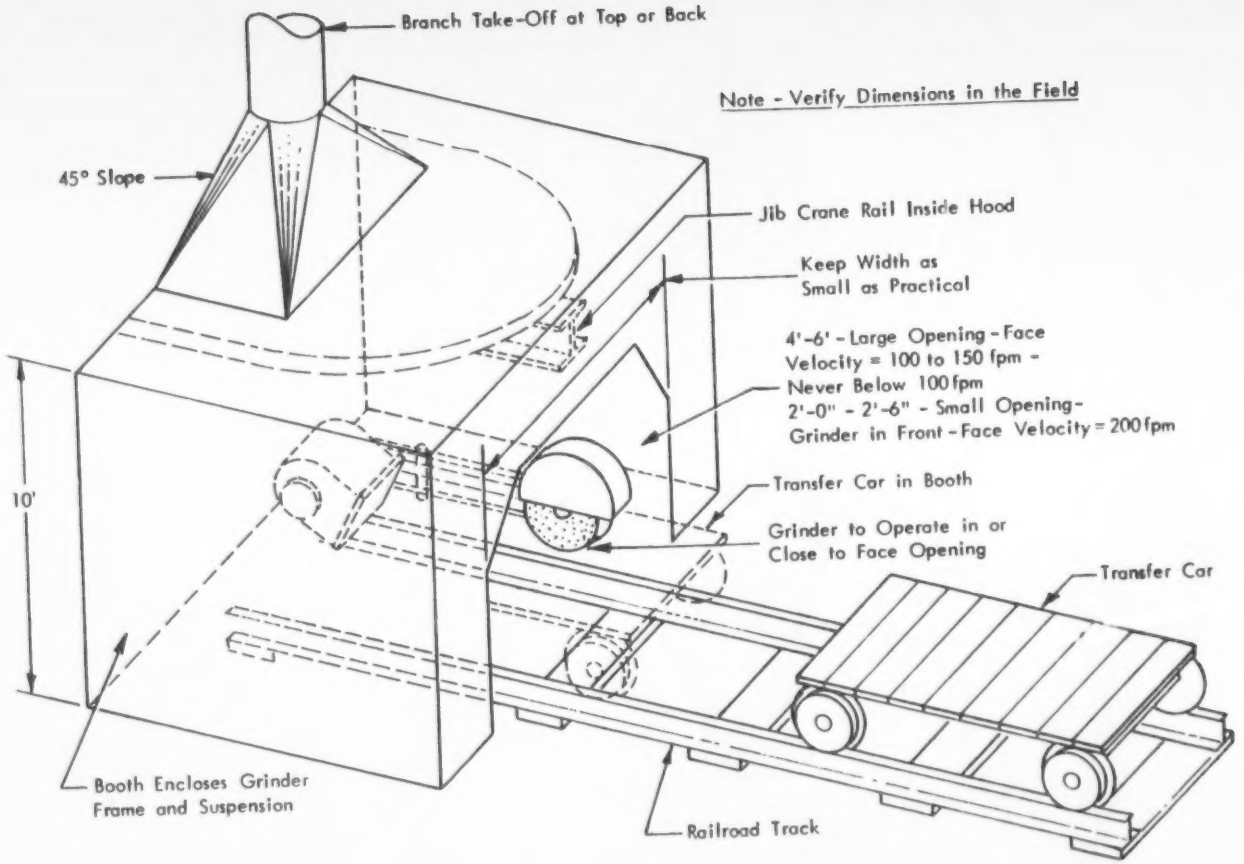

Branch Take-Off at Top or Back
Note - Verify Dimensions in the Field
45° Slope
Jib Crane Rail Inside Hood
Keep Width as
Small as Practical
4'-6' - Large Opening - Face
Velocity = 100 to 150 fpm -
Never Below 100 fpm
2'-0" - 2'-6" - Small Opening -
Grinder in Front - Face Velocity = 200 fpm
10'
Transfer Car in Booth
Grinder to Operate in or
Close to Face Opening
Transfer Car
Booth Encloses Grinder
Frame and Suspension
Railroad Track

Figure 4-13. Swing frame grinder booth with transfer car.[50/]

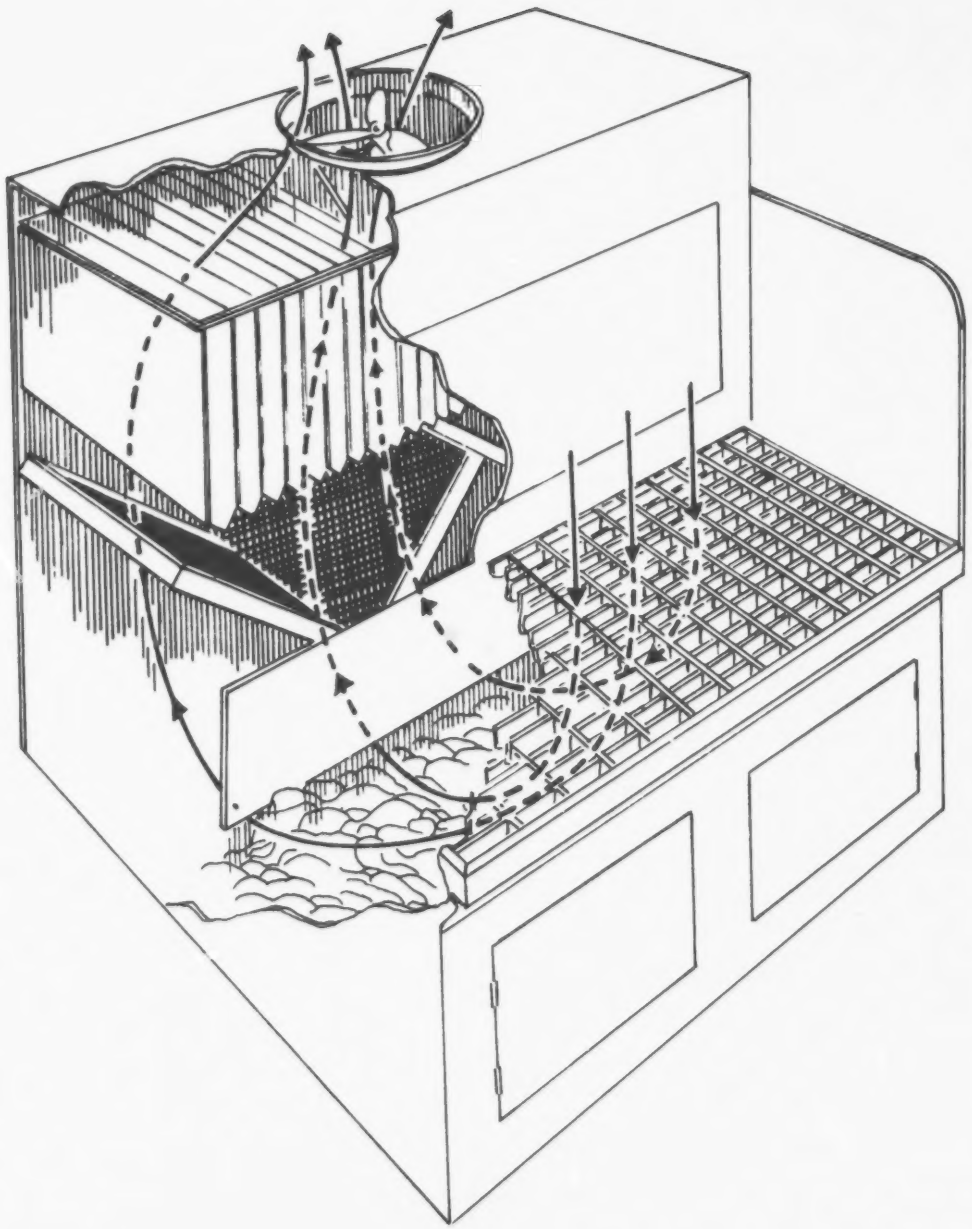


Figure 4-14. Downdraft grinding control.[51/]

Reference 50 suggests that enclosures can generally be used with grinders. However, care must be taken to ventilate the enclosure in such a way as to maintain clean worker breathing zones. It is assumed that wet scrubbers or fabric filters can be used with such enclosures.

4.4 MOLD AND CORE PREPARATION

Although particulate emissions are minimal in the core and mold preparation, the use of organic binders may create a hydrocarbon fugitive emissions problem. In cold box and green sand molding and core-making, emissions can be adequately controlled by proper direct venting of the process and hence are not a fugitive emissions problem. However, production of shell cores and molds and washing of all types of cores may produce fugitive emissions problems. Controls for these sources are discussed in the following paragraphs.

4.4.1 Sand Mixing or Mulling

The first step in the preparation of molds and cores is the mixing of sand and water or binders in a mixer or muller. Most emissions from mulling occur during loading. The moisture in the muller generally suppresses emissions once mixing begins. Reference 37 presents capture data for three types of mullers: no cooling, blow-through cooling and draw-through cooling. These data are presented in Figure 4-15. It is suggested that a wet scrubber (6- to 10-in. pressure drop) be used to remove the particulate from the emission stream. In general, emissions from sand mulling are well controlled to prevent exposure of operators to silica dust.

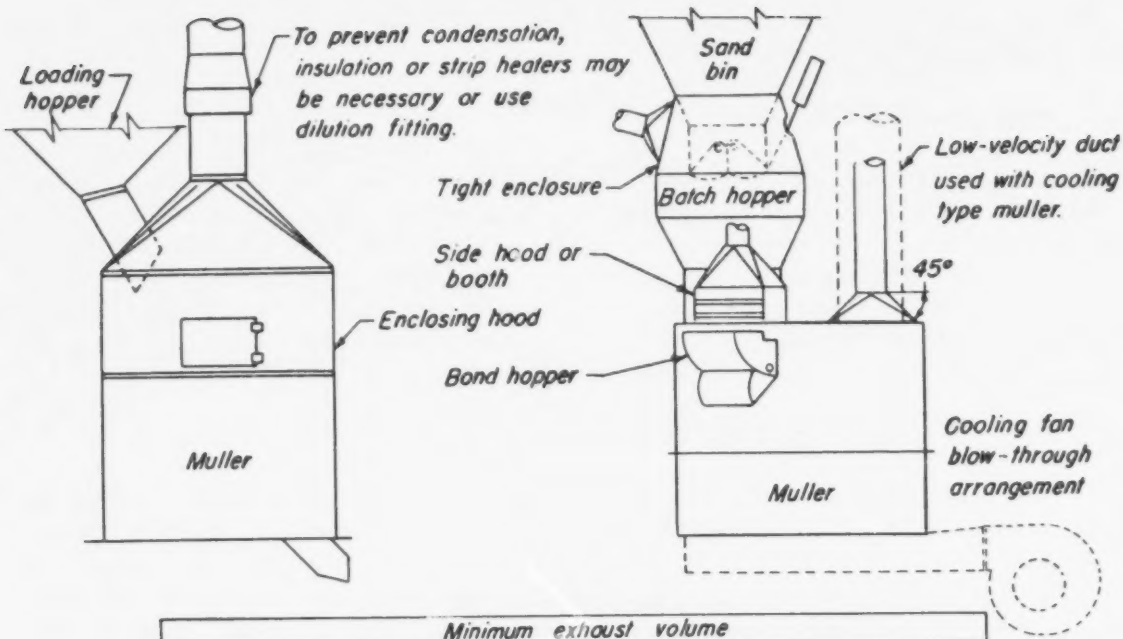
4.4.2 Shell Core and Shell Mold Making

Control of the shell core-making and molding process requires adequate ventilation of the shell-making machine and of the cooling area where cores and molds may continue to emit vapor for periods of up to 30 min.[37] In addition, an effective system for the removal of organic vapors from the pollutant stream is required. Since sand may be dry mixed, it may be necessary to control particulate emissions from this source.

4.4.2.1 Dry Sand Mixing--

Reference 15 suggests that dust produced from dry mixing of sand can be controlled by either exhaust ventilation or by using a wetting agent to suppress dusting. Addition of kerosene at the rate of 0.25% by weight is sufficient to minimize dust emissions.[15]

If a dust suppressant is not used, Reference 37 suggests that a closed type hood with flow rate of 1,000 cfm be used to capture emissions. Dust can be removed from the pollutant stream by use of either a scrubber (8- to 10-in. pressure drop) or a fabric filter.



Location	Minimum exhaust volume		
	Muller type		
	No cooling	Blow-thru cooling	Draw-thru cooling
Batch hopper	Note 1	600	Note 1
Bond hopper	600	600	600
Muller:	Note 2	Note 3	Note 3
4' diameter	750	"	"
6' diameter	900	"	"
7' diameter	1050	"	"
8' diameter	1200	"	"
10' diameter	1575	"	"

Duct velocity = 4500 fpm minimum
Entry loss = 0.25 VP

Notes:

1. Batch hopper requires separate exhaust with blow-thru cooling. With other fan arrangement, (muller under suction) separate exhaust may not be required. (If skip hoist is used, see VS-107)
2. Maintain 150 fpm velocity through all openings in muller hood. Exhaust volume shown are the minimum to be used.
3. Cooling mullers do not require exhaust if maintained in dust tight condition. Blow-thru fan must be off during loading. If muller is not dust tight, exhaust as in note 2 plus cooling air volume.

Figure 4-15. Mixer and muller ventilation.[37/]

4.4.2.2 Shell or Hot Box Core and Mold Heating--

The fugitive emission problem from the core-making and molding operations consists primarily of gaseous organics generated during heating and cooling of the cores and molds.

Since the core or mold machine cannot be adequately controlled by direct evacuation, adequate ventilation near the molding or core-making machine and in the mold or core cooling area is essential for effective control. The captured emissions must then be vented to a removal device capable of control of the organic gases.

An exhaust system for a shell-molding system as described as typical in Reference 15 is shown in Figure 4-16. Air velocities on the order of 150 to 250 fpm into all hood openings are suggested. It is likely that the hooding system shown is relatively effective in capturing emissions from the molding machine. However, it appears that the emissions generated during the transfer of the mold from the machine to the cooling table are not captured. In addition, the hood design shown in Figure 4-16 may be of limited effectiveness for controlling cooling emissions due to deviation of emissions from the shell and the need to remove shells from the table to make room for newly formed shells.

Lack of data on the total emissions from the molding process and on the temporal variation of these emissions makes estimation of capture efficiencies difficult. Reference 52 suggests that some molding area control systems have effectively captured odorous emissions with flow rates on the order of 5,000 acfm for a single molder. However, no data as to size of the area or points of pickup were reported.

Primary methods of removal of the organic pollutants from the emission stream are incineration and chemical absorption systems. However, it should be noted that many incinerators are being phased out due to energy shortages. Reference 52 briefly describes currently used design parameters for incineration and a possible chemical absorption system. These are described in the following paragraphs.

Reference 52 indicates that until recently, incinerators had been designed for 0.3 sec retention of shell fumes at 1200°F. However, tests in early 1975 showed that pollutant removal in these incinerators was not sufficient to effectively reduce odors in the surrounding area. Testing indicates that a retention time of 0.85 to 1 sec at 1500°F is necessary for effective hydrocarbon removal. The relative costs and efficiencies of these two designs for a 5,000-cfm system are given in Table 4-3.

Reference 52 goes on to describe a chemical absorption system for hydrocarbon removal which has been applied to shell core and mold operations at several foundries. The system, known as System 1, consists of single scrubbing tower using an acidic absorption solution in conjunction with a proprietary

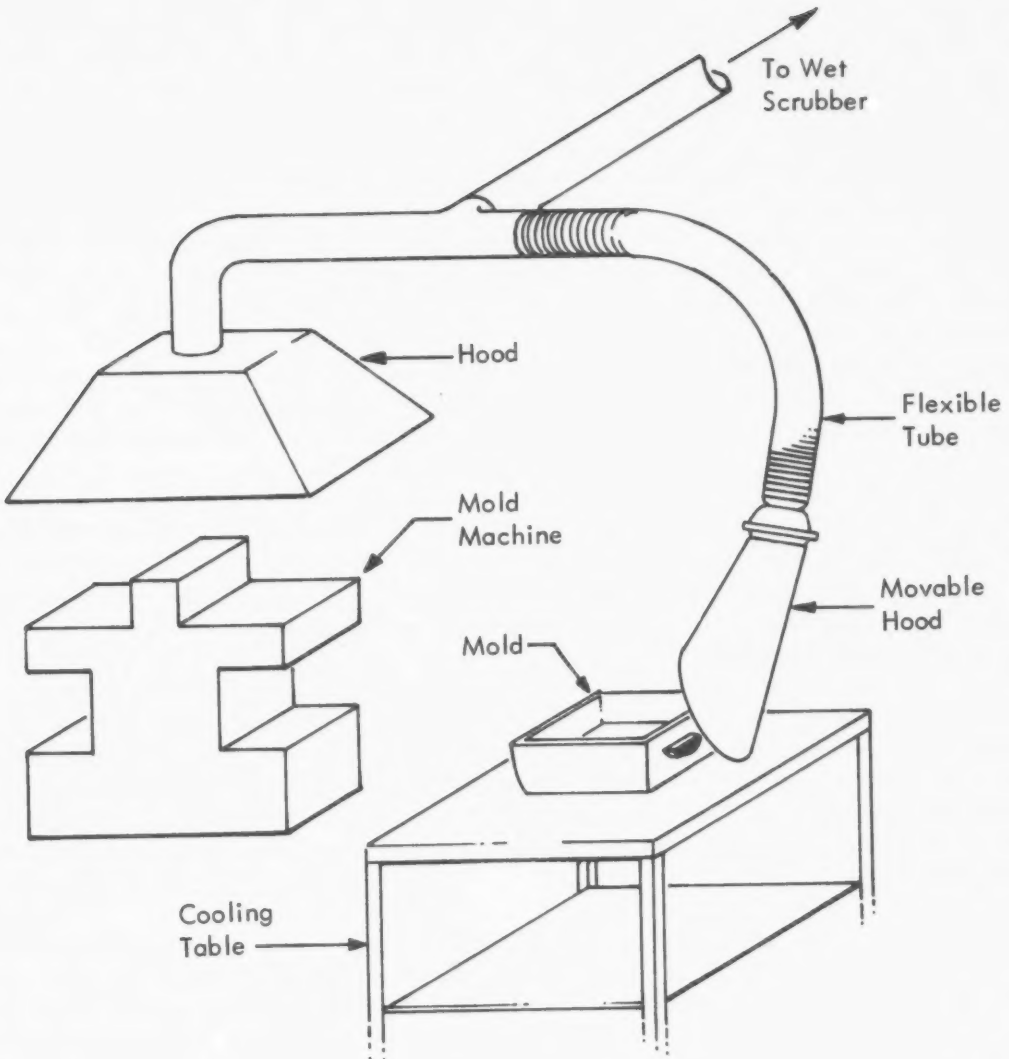


Figure 4-16. Control system for shell molding.

TABLE 4-3. POLLUTANT REMOVAL SYSTEMS FOR SHELLCORE AND MOLD MACHINES[52]

System	Pollutant concentrations (ppm)					Costs	
	CO	Formaldehyde	Amines	Ammonia	Phenol	Equipment $/cfm	Operating $/hr/$10^3$ cfm
No control	700	10	250	200	20	-	-
System 1	350	0	0	0	2	3.40	0.01
Standard incineration (1200°F, 0.3 sec)	3,000	8	200	150	20	4.25	1.68
Proper incineration (1500°F, 0.85-1 sec)	< 100	0	0	0	0	8.60	3.85

packing tempering agent that creates an ion exchange reaction in acidic solution. System maintenance requirements include filling the acid tank every 2 weeks, partial draining of the system once per week, checking the pH control every 2 weeks and completely draining and refilling the system twice per year.[52] Relative efficiency and cost of the system are given in Table 4-3.

4.4.3 Cold Box Core and Mold Making

No data were obtained on systems to capture and remove emissions from cold box systems.

4.4.4 Core Washing

Both organic and particulate emissions may be generated from core washing. Reference 37 suggests that spray booths are commercially available in all sizes. A flow rate of 100 to 175 cfm/sq ft of hood opening is suggested. It is currently general practice to duct the air stream from such booths directly to the atmosphere. Sufficient data on emission characteristics have not been obtained to recommend a removal device for this source.

4.5 WASTE HANDLING

Each of the waste handling operations in the foundry industry has the potential to generate particulate emissions. It appears that for the most part control methods should be aimed at minimizing emissions. Possible methods are described below.

4.5.1 Slag Quenching

No data were obtained on methods for control of emissions from slag quenching.

4.5.2 Waste Sand Transfer

Transfer of waste sand both within and away from the foundry can be controlled by adequate use of watering or chemical wetting systems. It is estimated that proper wetting can control internal transfer points with 90 to 95% efficiency.[22] A combination of wetting and covered transfer mode (conveyor or truck) can attain the same level of efficiency for external transfer. The initial cost of a spray system is estimated to be $10,000 to $15,000.[53] No data are available on operating costs.

4.5.3 Sand and Slag Storage

The primary points of emission from waste storage are load-in and wind erosion from storage areas. If proper wetting is attained for waste transfer, load-in emissions should be minimized. The following paragraphs describe methods for the elimination of emissions from wind erosion.

The process of stabilizing the surface layer of a pile consists of binding the surface particulates into a nonerodible crust. Occasional watering of the pile surface or the addition of chemical crusting agents will accomplish this task.

The control efficiency associated with periodic watering of the pile surface is estimated to be 80%, assuming that wetting of storage piles occurs on a regular basis.[22] Water spray systems may consist of stationary ground level sprinkler systems, tower-mounted sprinklers, or mobile tank-truck sprayer systems. An operating example is a stationary ground level system wetting two 900-ft long coal piles utilizing sprinkler heads spaced every 180 ft. Under dust producing meteorological conditions, the system of 32 sprinklers surrounding the piles sprays about 13,000 gal. of water per day. This system adequately controls wind erosion generation of fugitive dust.[54]

A sprinkler system mounted on a 30-ft tower producing a dense, 40-ft wide cloud of water mist has been used to minimize storage pile wind erosion at a quarry site. This system, which is both wind speed and direction activated, has produced favorable results.[55]

The control efficiencies associated with the spraying of surface crusting agents upon storage piles can extend to 99%, as derived from wind tunnel tests.[56] Surface crusting agents can be applied by either stationary or mobile sprinkler systems. Example chemicals and application rates for different types of these crusting agents are presented in Table 4-4.

The initial cost of erecting a stationary elevated water spray system, which controlled one relatively large stockpile, was estimated to be about $11,000, including sprays, piping, pumping, wind instruments, and installation costs.[55] No annual operating costs were obtained for this system.

The cost of applying surface crusting agents to storage piles from stationary equipment is assumed to be slightly more costly. This assumption is based on the need for additional mixing chambers and proportioners to dilute the crusting agents with water. The cost of applying these various surface crusting agents is presented in Table 4-4.

TABLE 4-4. EXAMPLE SURFACE CRUSTING AGENTS FOR STORAGE PILES AND EXPOSED AREAS[a/]

Surface crusting agent (concentrate)	Dilution	Application rate	Application cost[b/]
A. Organic polymers			
· Johnson-March, SP-301	Full strength	1 gal. concentrate per 100 ft^2	1.2¢
· Houghton, Rexosol 5411-B	2% solution	1 gal. concentrate per 300 ft^2	0.7¢
B. Petroleum resin water emulsion			
· Witco Chemical, Coherex	20% solution	1 gal. concentrate per 50 ft^2	0.4¢
C. Latex type-synthetic liquid adhesive			
· Dowell M145 chemical binder	4% water solution	4 gal. of 4% solution per 100 ft^2	0.4¢

a/ Reference 53.

b/ Cost per square foot of surface area.

SECTION 5.0

RESEARCH AND DEVELOPMENT RECOMMENDATIONS

Specific research areas which need investigation before adequate control of fugitive emissions in iron foundries can be accomplished are identified in this section. The flow diagram in Figure 5-1 depicts the methodology used to determine the research needs. Although the ultimate purpose of a research and development (R&D) program is the provision of appropriate technology for fugitive emissions sources, preliminary programs which identify levels and characteristics of these emissions may be necessary.

The first step in determining R&D needs is the identification of those sources which have emissions of sufficient severity to be considered a serious problem. For those sources identified in the initial step, availability of control techniques must be determined. If possible control techniques are available, the efficiency and cost of the techniques must be analyzed. Finally, for those research needs identified at each stage of the process, the adequacy of ongoing research to meet these needs must be determined.

The following subsections present information used to determine research needs in each of the above areas. Critical sources of emissions are determined and data gaps are identified; sources for which no control is available are identified; deficiencies in information on performance and cost of control techniques are evaluated; and ongoing research is examined. Finally, R&D programs are recommended.

5.1 DETERMINATION OF CRITICAL SOURCES

This section identifies those sources which have been determined to have the most critical emissions problem.

The severity of a fugitive emissions source in an iron foundry is dependent on: (a) the total particulate emission level; (b) the percentage of fine particulate (i.e., particles smaller than 5 μm); (c) the current extent of control; and (d) the presence of organic emissions. Each of these parameters is discussed and quantified below.

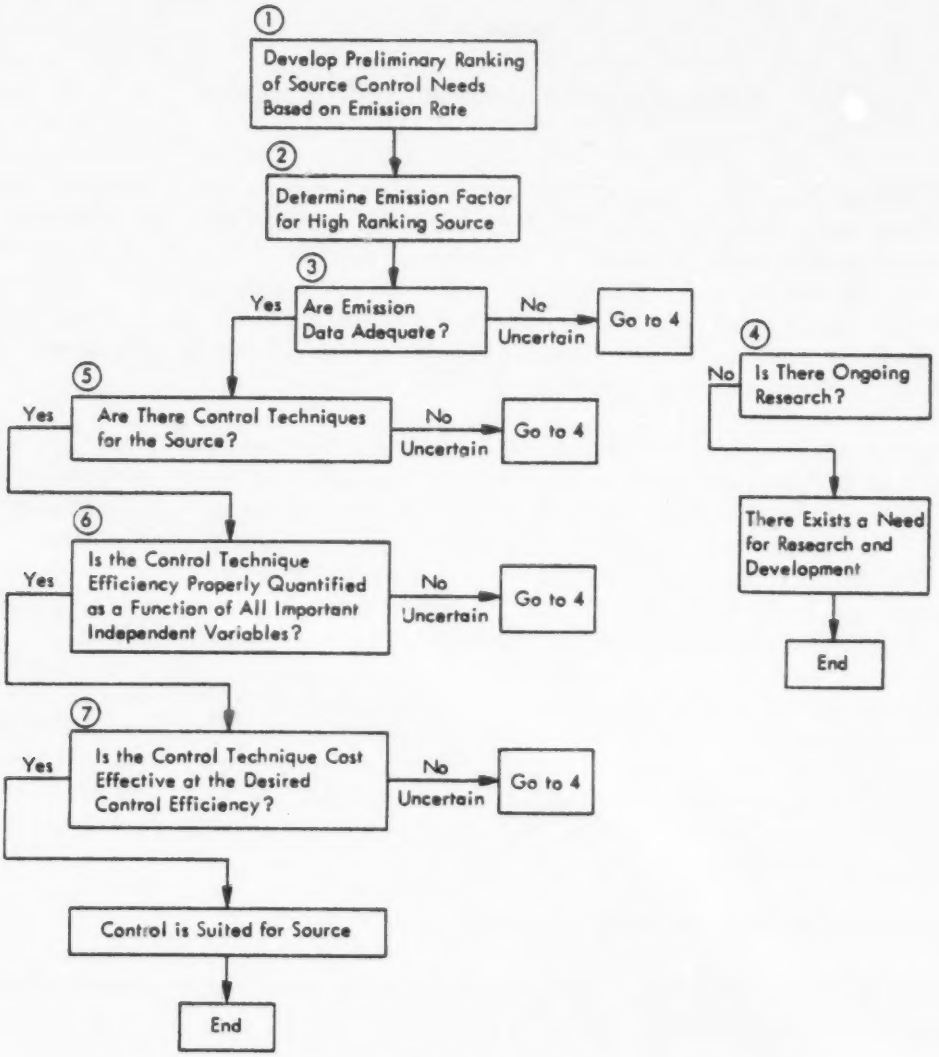


Figure 5-1. Flow diagram to determine the need for R&D.

An estimate of total particulate emissions and the percentage of fine particulate was developed for each of the major sources in iron foundries and presented in Table 3-2. The level of fine particulate emissions is important because fine particles are most hazardous to human health and that have greatest potential for atmospheric dispersion. Table 5-1 lists the major sources in descending order of uncontrolled fine particulate emissions.

In addition, MRI has developed estimates of the industry-wide extent of control for each source. This is a combination of capture efficiency and removal efficiency on an industry-wide basis and should not be construed to be applicable to a particular operation. These estimates are based on data presented by Gutow,[97] observations made by MRI personnel during plant visits, and conversations with industry personnel. These estimates are presented in Table 5-1 and a ranking of sources on a controlled basis is developed. It should be noted that these estimates are given a relatively low level of confidence and should be applied with great care to circumstances other than this ranking.

Based on the data in Table 5-1, those sources having the highest uncontrolled fine particle emission levels are:

1. Iron cooling
2. Iron pouring
3. Shakeout
4. Spent sand handling
5. Mulling

Those five sources having the highest ranking based on controlled fine particle emissions are:

1. Iron cooling
2. Iron pouring
3. Shakeout
4. Electric arc furnace
5. Iron inoculation

To this point, sources have been ranked strictly on the basis of particulate emission levels. However, it appears that several processes within the foundry industry are potential sources of organic emissions. Although industry

TABLE 5-1. RANKING OF PARTICULATE EMISSION SOURCES

Source No.[a]	Emission source	Uncontrolled fine particle emissions (lb/yr)	Extent of control (%)	Controlled fine particle emissions (lb/yr)	Ranking of controlled emissions
26	Iron cooling	9.0×10^7	10	8.1×10^7	1
25	Iron pouring	8.4×10^7	10	7.6×10^7	2
27	Shakeout	3.5×10^7	75	8.8×10^6	3
28	Spent sand handling	1.8×10^7	90	1.8×10^6	7
31	Mulling	1.7×10^7	90	1.7×10^6	8
18-20	Electric arc furnace	7.8×10^6	10	7.0×10^6	4
24	Iron inoculation	7.4×10^6	25	5.6×10^6	5
21-23	Induction furnace	2.2×10^6	10	2.0×10^6	6
10	Scrap storage	6.0×10^5	0	6.0×10^5	9
43	Waste sand transfer	5.1×10^5	0	5.1×10^5	10
44	Waste sand storage	4.2×10^5	0	4.2×10^5	11
33	Molding	4.2×10^5	0	4.2×10^5	12
44	Slag storage	8.1×10^4	0	8.1×10^4	13
5,6,8	Coke handling	7.8×10^4	50	3.9×10^4	14
16	Cupola tapping	-	-	-	-
7	Coke storage	Neg.	0	-	
15	Sand storage	Neg.	50	-	
30	Grinding	-	50	-	
37	Shell or hot box heating	-	-	-	
37	Shell or hot box holding	-	-	-	
38,39	Cold set mold and core	-	-	-	
41	Core wash	-	-	-	
42	Slag quench	-	-	-	

[a] See Table 2-2.

personnel contend that low in-plant organic concentrations indicate minimal emissions from some of these sources, data appear insufficient to warrant such a conclusion. The sources of organic emissions are:

1. Iron pouring

2. Iron cooling

3. Shell and hot box processes

4. Cold set operations

5. Shakeout

Data obtained during the study were not sufficient to quantify levels of organic emissions. Thus, it is not possible to rank these sources.

Based upon the analysis of both particulate and organic emissions, nine sources have been identified as representing possible critical control needs. These can be grouped into the following generic classifications:

1. Iron pouring and cooling

2. Shakeout

3. Sand handling operations (including mulling)

4. Electric arc furnaces

5. Iron inoculation

6. Core and mold preparation using organic binders

Since data throughout the industry are extremely limited, the response to Step 3 of the R&D flow chart is "no" for each source.

5.2 ANALYSIS OF CONTROL AVAILABILITY

Step 5 of the evaluation process asks the question, "are there control techniques for the sources"? In response, data developed in Section 4.0 have been used to determine the status of control capability for each major fugitive emission source in the foundry industry. The status of control of each source falls into one of three categories.

1. Standard methods of control are available and are generally or extensively applied around the industry.

2. Acceptable controls appear to be available but are not yet applied extensively throughout the industry.

3. Current state-of-the-art appears to be inadequate.

Those sources falling into the first category obviously have little need for control research. Research programs for the second source will deal with further analysis and development of available equipment. In addition the possibilities for the expanded use of the technology must be examined. Finally, for those sources falling in the third category, a major research effort directed toward the development of adequate and feasible methods may be needed.

The only source falling in the first category is the sand handling and mulling area. Data in Section 4.0 indicate that not only are control techniques available but they are also well engineered to meet performance requirements and are cost effective. Thus, available controls are suited for the source and no further research is needed.

Those sources with significant emission levels which fall in the second category include:

1. Electric arc furnaces

2. Iron inoculation

3. Shakeout (particulate emissions)

Those sources falling into the third category are:

1. Core and mold preparation using organic binders

2. Iron pouring and cooling

3. Shakeout (organic emissions)

For electric arc furnaces close capture hooding systems have been utilized in conjunction with fabric filters. These appear to adequately control fugitive emissions. However, further data are needed detailing the effectiveness of these systems. Additional information also needs to be developed on the engineering problems which may limit application of these systems.

Several methods have been developed which appear adequate for control of particulate emissions for iron inoculation. However, no data are available on either the extent of application of these methods or the effectiveness of the method.

Finally, shakeout particulate appeared to be well-controlled in about half of the operations observed during plant visits. However, this was based on visual operation and no substantive data have been found which indicate effectiveness of the various control systems. In addition, shakeout operations vary so greatly from plant to plant, that extensive study may be needed to determine the feasibility of application of shakeout controls to less mechanized foundries or those foundries preparing large castings. Little information is available on organic emissions or control for shakeout.

Few data, other than these obtained from a single control device manufacturer, are available on the availability of control systems for those core and mold preparation methods which utilize organic binders. In all foundries visited, these sources were not controlled and it is probable that they are not controlled in most iron foundries. The data available do not adequately describe an effective capture system.

No data are available on the adequacy or extent of application of any type of capture and removal system for either core washing or cupola tapping.

The control problems involved with iron pouring and cooling of molds are two-fold. For those foundries which utilize floor pouring, either because of size of castings or economic inability to develop mechanized lines, a technically and economically feasible capture system is necessary. For all types of pouring and cooling operations, an effective removal system is needed to handle the combination of moist particulate and organic emissions.

5.3 CURRENT RESEARCH

Knowledgeable personnel in the foundry industry and in governmental agencies were contacted to identify current research programs concerned with fugitive emissions quantification or control. A computer search of the Smithsonian Scientific Information Exchange files was also conducted to identify pertinent research programs listed there. Only three relevant research programs were identified. These are summarized in Table 5-2.

The most significant studies appear to be the NIOSH study conducted by Envirex and the EPA study conducted by Research Triangle Institute (RTI). The Envirex study is an extensive analysis of the state of the art of internal foundry emission control technology. Most sources covered are identical to those identified as fugitive emissions sources in this report. However, the Envirex study will be primarily concerned with an analysis of capture or abatement mechanisms. With the help of the foundry industry the 30 to 40 best control foundries have been identified. Thirty of these plants will be chosen for further analysis. At each of these plants control equipment design data, effectiveness and application problems will be identified. It is suggested that the results of this project be carefully analyzed by EPA personnel. Little information was obtained on the RTI study.

TABLE 5-2. CURRENT RESEARCH

Research group	Sponsoring organization	Program summary	Program status
A. D. Little Company	EPA	Study of economic impacts of air pollution regulations on the foundry industry.	To be completed 1979. Have completed a macro-analysis. Beginning a micro-analysis for specific processes.
Envirex	NIOSH	A study of the state of the art of internal foundry control technology. The control systems are to be analyzed at the 30 best controlled foundries in the U.S.	Have identified 30 foundries. Study to be completed in late 1978.
Research Triangle Institute (RTI)	EPA	A multimedia assessment of iron foundry processes and their related pollution control technologies with particular attention directed toward organic emissions.	Study to be completed in mid-1979.

5.4 SUGGESTED RESEARCH

Based upon the ranking developed in Section 5.0 and the emissions data and control technology deficiencies discussed above, R&D programs are suggested for four types of sources in iron foundries. In order of priority these are:

1. Pouring and cooling
2. Electric arc furnaces
3. Core and mold preparation using organic binders
4. Shakeout

The pouring and cooling of iron castings in sand molds is by far the most significant problem in the industry and will require the greatest effort to develop emissions control technology. As indicated earlier two basic methods are used for pouring and cooling. The first method utilizes a fixed pouring station which is normally hooded. The molds are moved to the pouring station by conveyor and into a cooling tunnel which is vented. In almost all cases, the ventilation systems for pouring and cooling are vented without pollutant removal to the atmosphere. The second method, floor pouring and cooling is conducted in an open area with molds placed on the floor and pouring ladles moving to the mold for pouring. Generally, no control is applied to these sources. This method is used in smaller, older foundries and in cases where the mold and casting are too large to be moved by conveyor.

The basic control technology deficiencies for these sources are (a) lack of emissions data, (b) unavailability of a capture system for floor pouring and cooling, and (c) insufficient removal systems for either floor pouring or fixed pouring stations. The tasks which must be accomplished to effectively deal with the problem are:

1. Definition of the emissions problem. This will include data to define total particulate and gaseous emissions, type of organic vapors emitted, particle size distribution, moisture content of emissions stream, temporal variation of emissions during pouring and cooling. Some of these data have been developed for a bench scale system by Bates and Scott,[11] but no data are available for full-scale operation.

2. Development of a technically and economically feasible capture system for floor pouring and cooling.

3. Development of an effective removal system for the captured emissions stream. This should include an analysis of any systems currently used on pouring or cooling lines. No published data are available for such systems.

Electric arc furnaces emit fine metallic fumes to the foundry and eventually to the atmosphere during charging, tapping, and meltdown from leakage around the electrodes. A close capture hooding system is described in Section 4.0 which visually appears to effectively capture these emissions. However, the system has been applied only to a limited number of EAFs and no test data are available. Canopy hooding systems have also been applied to EAFs with some degree of effectiveness, but again no actual data to determine the effectiveness of canopy hoods are available.

The tasks which must be completed to allow foundry personnel to determine the best method for controlling EAF fugitive emissions are:

1. Development of an adequate methodology for testing uncontrolled and controlled emissions from EAFs and testing of uncontrolled emissions and the effectiveness of close capture and canopy hoods.

2. Determination of technical limitations for application of both close capture and canopy hood systems.

3. Evaluation of the economic impact of both systems on foundries which currently have uncontrolled EAFs.

The primary fugitive emissions problem in the core and mold preparation area is the evolution of organic gases from operations using organic binders. Data on the quantities of organics emitted from these sources and the effectiveness of control systems are not adequate. It is suggested that the problem should be further defined and the significance of these sources should be determined before control technology research can be justified. The tasks which need to be accomplished to define the problem are:

1. Development of an inventory of core and mold production processes and the type of binders used on a geographic basis.

2. Determination of total organics emitted and the compounds present for each major process.

3. Determination of emissions levels on a geographic basis and evaluation of the significance of the source.

It appears that this program may be covered in part by the RTI study.

Effective controls appear to have been developed for many shakeout operations. However, lack of accurate emissions data prevents analysis of the effectiveness of these controls. The first task in any program should be the determination of emission levels on a full-scale shakeout and the effectiveness of available control systems. After this has been completed, those foundries not

employing fugitive controls should be analyzed. Methods should then be determined for control of emissions at these foundries.

In summary, the four areas for which R&D programs are needed are: (a) iron pouring and cooling, (b) electric arc furnaces, (c) mold and core preparation processes utilizing organic binders, and (d) shakeout. Adequate testing methods must be developed to quantify emissions from these sources and to determine the effectiveness of alternative control methods.

SECTION 6.0

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SECTION 7.0

GLOSSARY

Duration of Storage - The average time that a unit of aggregate material remains in open storage, or the average pile turnover time.

Dust Suppressant - Water or chemical solution which, when applied to an aggregate material, binds suspendable particulate to larger particles.

Emission Control System, Primary - A control system installed to capture and remove most of the total emissions prior to atmospheric discharge.

Emission Control System, Secondary - A control system designed to capture and remove the smaller portion of the total emissions that the primary system does not collect with the smaller portion usually being fugitive in nature.

Enclosure - A structure which either partially or totally surrounds a fugitive emissions source thereby reducing the amount of emissions.

Fugitive Emissions, Total - All particles from either open dust or process fugitive sources as measured immediately adjacent to the source.

Fugitive Emissions - Emissions not originating from a stack, duct, or flue.

Load-In - The addition of material to a storage pile.

Load-Out - The removal of material from a storage pile.

Materials Handling - The receiving and transport of raw, intermediate and waste materials, including barge/railcar unloading, conveyor transport and associated conveyor transfer and screening stations.

Moisture Content - The mass portion of an aggregate sample consisting of unbound moisture on the surface of the aggregate, as determined from weight loss in oven drying with correction for the estimated difference from total unbound moisture.

Partial Diameter, Aerodynamic - The diameter of a hypothetical sphere of unit density (~1 g/cm^3) having the same terminal settling velocity as the particle in question, regardless of its geometric size, shape, and true density.

Particle Diameter, Stokes - The diameter of a hypothetical sphere having the same density and terminal settling velocity as the particle in question, regardless of its geometric size and shape.

Particulate, Fine - Airborne particulate smaller than 5 μm in Stokes Diameter.

Particulate, Suspended - Airborne particulates smaller in Stokes diameter than 30 μm, the approximate cut-off diameter for the capture of particulate matter by a standard high-volume sampler, based on a particle density of 2 to 2.5 g/cm^3.

Precipitation-Evaporation Index - A climatic factor equal to 10 times the sum of 12 consecutive monthly ratios of precipitation in inches over evaporation in inches, which is used as a measure of the annual average moisture of a flat surface area.

Source, Open Dust - Any source from which emissions are generated by the force of wind and machinery acting on exposed aggregate materials.

Source, Process Fugitive Emissions - An unducted source of emissions involving a process step which alters the chemical or physical characteristics of a material, frequently occurring within a building.

Silt Content - The mass portion of an aggregate sample smaller than 75 μm in diameter as determined by dry sieving.

Spray System - a device for applying a liquid dust suppressant in the form of droplets to an aggregate material for the purpose of controlling the generation of dust.

Storage Pile Activities - Processes associated with aggregate storage piles, specifically, load-in, vehicular traffic around storage piles, wind erosion from storage piles, and load-out.

Surface Stabilization - The formation of a resistive crust on an exposed aggregate surface through the action of a dust suppressant, which suppresses the release of otherwise suspendable particles.

SECTION 8.0

ENGLISH TO METRIC UNIT CONVERSION TABLE

English unit	Multiplied by	Metric unit
lb/ton	0.500	kg/ton
lb/vehicle mile	0.282	kg/vehicle km
lb/acre year	112	kg/km^2 year
lb	0.454	kg
Ton	0.907	ton
mph	0.447	m/s
mile	1.61	km
ft	0.305	m
acre	0.00405	km^2